JPL NO. 9950-509

DOE/JPL 954865-80/9

Distribution Category UC-63
DRL No. 51, DRD Item No. 11b

PHASE 2
ARRAY AUTOMATED ASSEMBLY TASK
LOW COST SILICON SOLAR ARRAY PROJECT

Final Report
December, 1980

JPL Contract No. 954865

Clayton Olson

PHOTOWATT
INTERNATIONAL, INC.

2414 West 14th Street
Tempe, Arizona 85281

PHASE 2

ARRAY AUTOMATED ASSEMBLY TASK
LOW COST SILICON SOLAR ARRAY PROJECT

Final Report
December 1980

Clayton Olson

JPL Contract No. 954865

Sensor Technology, Incorporated
21012 Lassen Street
Chatsworth, California 91311

and

Photowatt International, Incorporated
2414 West 14th Street
Tempe, Arizona 85281

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement with NASA and DOE."

PREFACE

The information presented in this Final Report provides a summary of the work performed from September 20, 1977 through June 30, 1980 by Sensor Technology, Inc., in Chatsworth, California and Photowatt International, Inc. in Tempe, Arizona.

The program was directed by Sang S. Rhee from Sensor Technology and Sanjeev Chitre from Photowatt International, Inc. Principal contributors included Sanjeev Chitre, Kimberly L. Allison, Gregory T. Jones, Charles Snyder, Louis R. Rosinski, Nelson E. David, and A. PeBenito. Also contributing to the work performed on the Laser Trimming and Holing Operation and the Spray-on Dopant Tasks were Robert A. Kaplan from Quantronix Corporation and Jeffrey Dexter from Advanced Concepts Equipment Corporation, respectively.

The JPL Technical Program Managers during this report period were Paul Alexander, Clayton Olson and Ed Drouet. Judy Spencer acted as the Technical Manuscript Coordinator and was responsible for the formatting and typing of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continuation)

TABLE OF CONTENTS
(Continuation)

TABLE OF CONTENTS
(Continuation)

TABLE OF CONTENTS
(Continuation)

TABLE OF CONTENTS
(Continuation)

TABLE OF CONTENTS
(Continuation)

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

I. INTRODUCTION

The worked performed under this contract was part of the DOE/JPL Low-Cost Solar Array (LSA) Project. The primary objectives of the program are to demonstrate and, where necessary, to develop those solar cells and module process steps which have the technological readiness or capability to achieve the 1986 LSA goals.

Large volume, high throughput rates and automation are necessary to achieve the 1986 cost goals low-cost qualifications for solar cell and module production companies. The 1986 LSA industry production goals are 500 megawatts per year at 70 cents per peak watt in 1980$. Consequently, a major effort in this contract was applied toward the analysis of solar cell and module process steps for throughput rate, cost effectiveness and reproducibility. The analysis was based upon the assumptions listed below:

(1) 500 MW/year are produced in 1986 (the specific year was not critical to this study) at $.308/watt in 1980 dollars for silicon wafer material and at $.70/watt in 1980 dollars for the finished module.

(2) Two vertically integrated companies, CELLCO a solar cell production firm and MODULCO a module production firm, will share 40 percent of the market, 200 MW, and MODULCO will buy 100 percent of its solar cells from CELLCO.

(3) CELLCO and MODULCO require an average of 4.7 person-shifts per day and operate 24 hours per day, 7 days per week, 345 days per year.

(4) The solar cells will have at least a 14.7% encapsulation efficiency and a production yield of at least 95%.

(5) The module will have the dimensions of 2' x 4', will contain 119 equivalent modified hexagonal solar cells (102 full cells and 34 half cells), and will have a power output of 90 watts at 100 mW/cm^2 solar insolation.

As a result of the above, nominal throughput is expected to be as follows:

CELLCO:	278 million solar cells per year or 210.3 MW per year
MODULCO:	2.222 million modules per year or 200 MW per year

In addition to the concentration on cell and module processing sequences, an investigation was made into the capability of using microwave energy in the diffusion, sintering and thick film firing steps of cell processing.

Although the entire process sequence has been integrated, the steps are treated individually with test and experimental data, conclusions and recommendations together in one subsection.

Sensor Technology, Inc. is no longer directly in the terrestrial solar photovoltaics field. Their entire effort in this area has been assumed by Photowatt International. It must be acknowledged, however, that while reference is made throughout this report to Photowatt CELLCO and MODULCO, the bases for many of these determinations were with Sensor Technology.

II. SUMMARY

The initial contract was a Phase II Process Development for a process sequence, but with concentration on two particular process steps: laserscribing and spray-on junction formation. The balance of the process, although important, was to be a subordinate level of effort to support these two major tasks.

The add-on portion of the contract was to further develop these tasks, to incorporate spray-on of AR Coating and aluminum and to study the application of microwave energy to solar cell fabrication.

The overall process cost projection is 97.918¢/Wp. The major contributor to this excess cost is the module encapsulation materials cost. The frame and encapsulation materials alone total 25.634¢/Wp. Since this was not an area of major effort on the contract, the approach was to automate what was available, not to develop new technologies and, as a result, less effort was devoted to this task.

During the span of this contract the study of microwave application to solar cell fabrication produced the ability to apply this technique to any requirement of 600°C or less. Above this temperature, non-uniformity caused the processing to be unreliable. It became evident that fundamental development efforts were required and these are being pursued through another contract.

The "Technical Discussion" section of this report only concerns itself with costs when these have been driving forces that directed the area of technology in which efforts had to be expended.

Following the "Technical Discussion" section, the "SAMICS Analyses" section details, in written form, the processes that go into the final sequence of SAMICS Format A's which appears in Appendices II and III.

The "Process Specifications" section details the processes which were fully developed for this program. These have been written for engineering personnel and not as operator oriented documents. A normal level of familiarity with the proper handling of chemicals, equipment and product is assumed. If it is desired to implement any of these processes, the engineer is cautioned that adequate safety instructions and "right hand/left hand" additions to the specifications are required for some production levels of familiarity.

III. TECHNICAL DISCUSSION

A. Wafer Surface Preparation

Wafer surface preparation plays an important role in solar cell power output. In addition to reducing reflection losses from the front surface of solar cells, the texturizing process prepares the silicon wafers for the subsequent junction formation step. From the experimental results of this program and from work reported elsewhere,[1,2] it was demonstrated that the wafer surface preparation process yields silicon wafers which have black antireflective surfaces, which are uniformly etched and are batch-to-batch reproducible.

The wafer surface preparation equipment shown in Figure 1 also demonstrated a high throughput rate; it can process, after the initial startup time, 2400 wafers per hour.

The wafer surface preparation process consists of five steps. They are (1) wafer surface cleaning, (2) surface macrostructure etching, (3) four-stage cascade rinse, (4) surface macrostructure final cleaning, and (5) final rinse/spin dry.

Ninety millimeter diameter, Czochralski (100) as-cut, round silicon wafers were procured and sample inspected for experimentation. They were manually placed into cassettes which hold twenty-five wafers. Four cassettes or one hundred silicon wafers were manually loaded into a carrier basket ready for the first process step.

The first step in the wafer surface process consists of a two-stage wafer surface cleaning procedure. The silicon wafers are placed into trichlorethylene (at room temperature) for five minutes (preferably in an ultrasonic tank) followed by a five minute methanol dip. Since

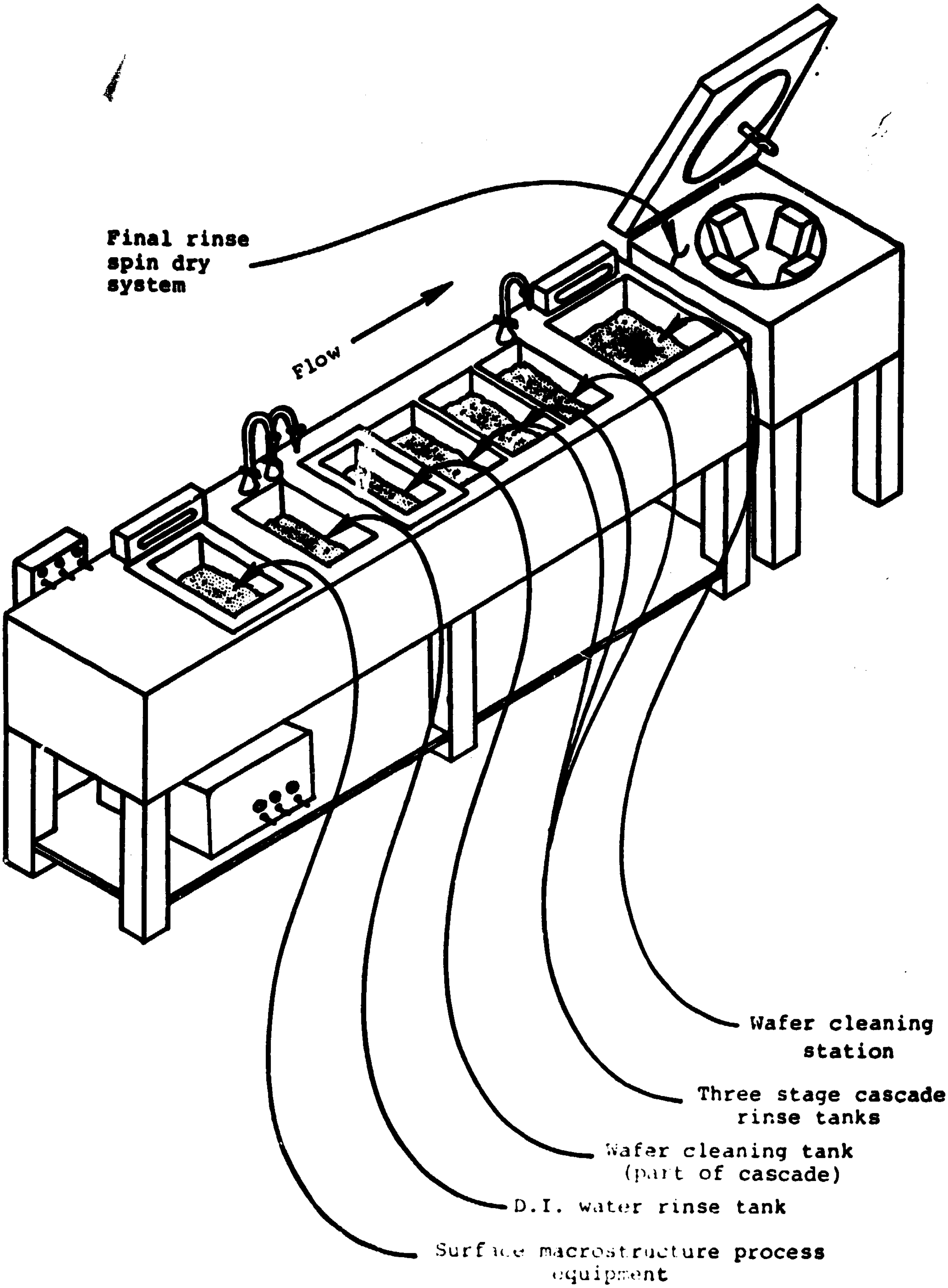


Figure 1. Sketch of Surface Macrostructure Process Equipment.

9 liters are used in these processes, and the solutions are replaced every eight hours (as an operational convenience) the usage in both cases is 0.9 cc/wafer. This process step cleans organic contaminants off the wafer surfaces which might otherwise impede the surface preparation etching step.

The second step in the wafer surface preparation process is surface macrostructure etching. The carrier basket containing the silicon wafers is introduced into an ultrasonic stainless steel tank which has been filled with a 10% (w/w) solution of NaOH in deionized water at $85^{o}C \pm 2^{o}C$. Suspended in the tank is a nitrogen bubbler in addition to the ultrasonics. Ten liters per minute of nitrogen gas are required for the bubbler designed by Sensor Technology, Inc. It is to be noted that the design and placement of the bubbler, with respect to the silicon wafers, determines the consistency of the surface macrostructure etching process. A large amount of nitrogen bubbles, which are small in diameter, contributes to uniform surface macrostructures. The process time for this step is five minutes.

The carrier basket is manually removed from the surface macrostructure etching tank and placed into the first ultrasonic stage of a four-stage cascade rinse system which makes up the third step in the process. The carrier basket remains for five minutes in each of the four stages. Hot deionized water flows at a rate of 3.8 liters per minute from the fourth stage where the D.I. water input temperature is $80^{o}C \pm 5^{o}C$ to the first ultrasonic stage where the D.I. water output temperature is $72^{o}C \pm 5^{o}C$. The silicon wafers get progressively cleaner as they move from the first stage to the fourth stage of the cascade rinse system.

The fourth step in the wafer surface preparation process is final cleaning. The wafer jigs are manually removed from the cascade rinse and introduced into a sulfuric acid/hydrogen peroxide mixture (1:1) at $70^{\circ}C \pm 5^{\circ}C$ for five minutes (30% H_2O_2, not stabilized). This solution removes any remaining deposits of sodium hydroxide that may be trapped in the wafer surface. The wafers are then rinsed off in running D.I. water for five minutes.

The fourth wafer surface preparation process step was found to be $38.00/500 wafers. It was also found to have only a minor effect on solar cell electrical performance. Since it is essentially a precautionary measure to ensure the cleanliness of the texturized silicon wafers and, under this optimized wafer surface preparation process, the final cleaning step should not be necessary; it is recommended that this process step not be considered in the overall 1986 wafer surface preparation process.

The last step in the wafer surface preparation process is the final rinse/spin dry. The last remaining wafer surface contaminants are removed in this five minute cycle. The wafers are now ready for the junction formation process.

The wafer surface preparation process demonstration equipment was used to process 100 ninety millimeter diameter silicon wafers for each carrier basket or four cassettes carrying 25 wafers each. The system capability is 200 wafers per process step (including transfer time) assuming two layers of 100 wafers each. The wafer surface preparation process therefore can produce, after the initial startup time, 2400 wafers per hour.

A SAMICS cost analysis was performed on this task and showed a total cost of 2.09 cents per peak watt in 1980 cents for a fully automated system with a wafer throughput of 6000 wafers per hour. Included in the analysis is the elimination of the final cleaning step (step 4 above) and the replacement of the final rinse/spin dry step with a clean air blow dry system.

A detailed cost analysis is discussed in a later section. It can be concluded that the wafer surface preparation process will contribute significantly to reducing the cost and increasing the solar cell and module efficiency which is in-line with the 1986 LSA goals.

B. Spray-on Dopant Junction Formation

The spray-on dopant process is a low-cost, innovative junction formation technique which appears to have a high potential for achieving the 1986 LSA program goals. Several features of the equipment contribute to the favorable prospects of the spray-on dopant junction formation technique. Among these characteristics are the high wafer throughput rate and the reasonably short processing time obtainable from the prototype spray-on dopant equipment. An important feature of the spray-on dopant equipment is its adaptability to large-scale production. An equally important feature of the prototype equipment is its capability of performing a wide range of parametric variations which lead to process optimization. The following sections present a detailed description of the prototype spray-on dopant equipment, as well as documentation of the process study.

B1. Spray-on Dopant Equipment

The spray-on dopant equipment utilized by Photowatt International is the Model 100 SC Precision Spray-on Coating and Drying System which was designed and constructed

by Advanced Concepts Equipment, a Division of Huestis Machine Corporation, Bristol, Rhode Island. This system was specifically designed for the purpose of spraying thin film dopants onto silicon wafers. An illustration of it can be found in Figure 2.

The system is capable of processing approximately one sq. ft. per minute, allowing 65% utilization of the conveyor area. In order to provide a more economical system which maintains all the essential controls of the sophisticated spray-on equipment, the support frame was reconstructed as a bench-type model with open access. It has the capability of providing a high degree of uniformity between successive coating batches due to a manually selected flush subsystem which cleans the internal passages, filter and nozzle orifice of the spray gun after the coating cycle. Good thickness and leveling control can be attained as a result of the many overlapping passes of the spray gun. Important parameters such as conveyor speed, coating material flow rate, air or nitrogen flow rate (atomization) and I.R. emitter temperature are fully adjustable. All functions are controlled by conveniently located switches and regulators.

The coating and drying system consists of six components, each of which performs a specific function. The loading station is 12" long and accessible from three sides. The conveyor system will transport manually loaded pallets containing six wafers each, through the spraying operation, drying tunnel and finally onto the unloading station. It is driven by an explosion-proof motor and adjustable speed reducer which will provide conveyor speeds of 0.3 to 3 feet per minute.

The spray chamber houses the air atomization spray gun which can dispense both the coating material and the cleaning solvent as the result of a special valving arrangement which has the additional advantage of facilitating

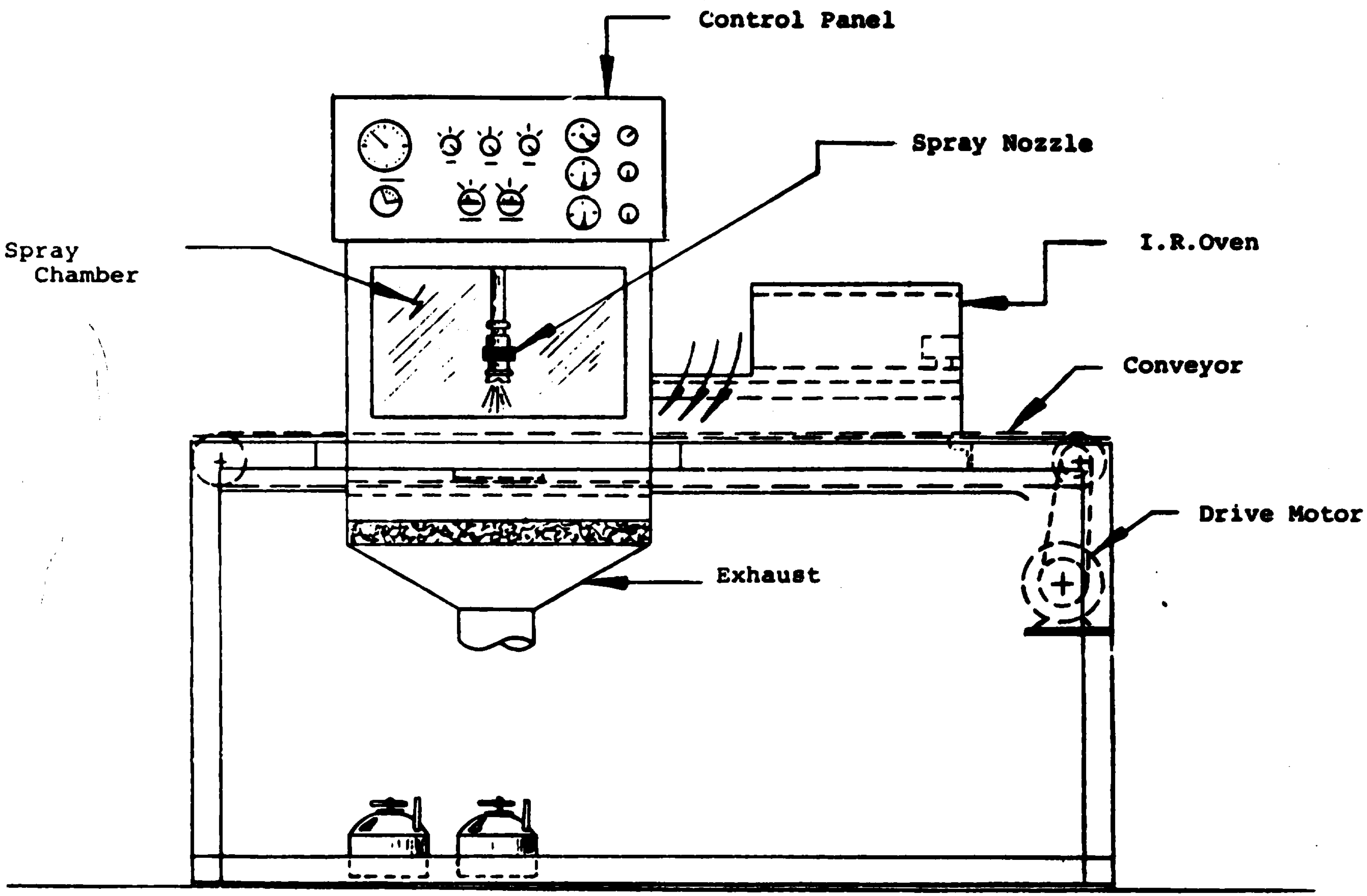


Figure 2. Sketch of Spray-on Dopant System Model.

selective control of the spray/flush sequence. The spray chamber has a rectangular cross-sectional area of 24" by 27", and a height of 16". The conveyor entry and exit openings extend 2" in height. An exhaust plenum located in the lower portion of the spray chamber serves to maintain the cleanliness of the chamber through the use of overspray pans and an exhaust filter.

The air dry station, located between the spray chamber and the IR/convection drying tunnel, is fabricated from type 304 stainless steel. The special environment maintained in the "air dry" station hinders the formation of "pin holes" on the substrates during the subsequent elevated temperature drying cycle by evaporating the more volatile solvents from the coating. The drying tunnel is constructed of stainless steel and utilizes both convection and IR radiation to cure the thin-film coating.

The infra-red radiation output of the heater panel is independently regulated by a solid state temperature controller which provides a maximum variation of $\pm$ 2% at a maximum temperature of 800^{o}F, The heater panel is covered with fiberglass insulation to minimize thermal radiation leakage to the outside enclosure. Unlike many conventional IR heat sources, this panel heater has been specifically designed for explosion-proof operation in an environment of concentrated organic solvent vapors such as that encountered in the drying tunnel. To minimize the concentration of solvent vapors within the oven tunnel, an air flow of approximately 50 linear feet per minute is used. The spray booth exhaust is used to facilitate this requirement. The unloading station, like the loading station, is 12" long and accessible from three sides.

B2. Mechanical Parameter Optimization

Upon delivery and installation of the spray-on dopant equipment at Sensor Technology, tests were devised which set out to optimize the following key mechanical parameters:

Parameter	Symbol	Test Span
• Conveyor Speed	V_c	1/2 ft/min., 5 ft/min
• Nozzle Speed	V_n	45-90 osc/min
• Dopant Pot Pressure	P_d	to deliver 5 to 15 cc/min
• Atomization Pressure	P_a	15 psig - 35 psig
• Baking Temperature	T_o	400^oF fixed
• Nozzle Diameter	D_n	.010", .015", .020" dia.

The uniformity of the dopant spray is strongly dependent upon V_c, V_n, P_a and D_n. The pot pressure, P_d, controls the dopant consumption rate, and the IR oven temerature, T_o is adjusted to coordinate with the conveyor speed for proper curing of the thickness of the dopant layer on the wafer surface. Each of these parameters is also dependent upon the type of dopant material utilized in the dopant survey. The two types of dopant materials used in the experimental studies are as follows:

a. Emulsitone N250, water based phosphosilicia film
   Viscosity: 22 centipoise
   Concentration: 1×10^{18}, 1×10^{19}, and 5×10^{19} atoms/cm^3

b. Emulsitone borosilica film, water based
   Viscosity: 32 centipoise
   Concentration: 1×10^{19} and 1×10^{20} atoms/cm^3

By utilizing the above mentioned dopant solutions on texturized wafers, tests succeeded in optimizing all mechanical parameters. The dopant concentration was found not to change parameters, which were:

a. The optimum nozzle speed, V_n, was 50 strokes per minute at a maximum conveyor speed, V_c, of 2 feet per minute.

b. The optimum atomization pressure, P_a, for a dopant flow rate of 7 cc/min. was 18 psig. For a dopant flow rate of 10 cc/min. the optimized pressure, P_a, was 25 psig.

c. The optimum baking temperature, T_o, for all test conditions was 375^{o}F.

d. The optimum nozzle diameter, D_n, for both dopants was 10 mil.

e. The optimized dopant pot pressures, P_d, for three different phosphosilica and boron dopant flow rates and film thicknesses are shown in Table 1.

B3. Dopant Flow Rate Versus Solar Cell Electrical Performance

The mechanical parameter optimization study prompted a further investigation which was designed to assess the relationship between the phosphosilica dopant flow rate and the solar cell electrical performance. Three batches of solar cells were used in the experimental study. All spray-on dopant process parameters were fixed as shown in Table 2 with the one exception of the dopant flow rate, in order to evaluate the effect of dopant flow rate variations on solar cell electrical performance. (The atomization pressure was increased from 18 psig to 25 psig in Batch 3 in order to prevent the non cut-off effect and thus optimize the atomization pressure.)

When the electrical performance test results were evaluated for the round solar cells, the fill factors and efficiencies were found to be very poor. A dopant overlap was suspected. Hexagonal solar cells were cut by laserscribe from the round solar cells and a much improved electrical performance was observed as shown in Table 3. The fill factors

Table 1. Experimental Data Relating the Optimized Dopant Pot Pressure, P_d, with Three Different Phosphosilica and Boron Dopant Flow Rates and Film Thicknesses.

PHOSPHOSILICA DOPANT			
Dopant Flow Rate: Pot Pressure: P_d etc Thickness:	5 cc/min. 65" H_2O 4μ	7 cc/min. 95" H_2O 8μ	10 cc/min. 145" H_2O 15μ
BORON DOPANT			
Dopant Flow Rate: Pot Pressure: P_d Thickness:	5 cc/min. 48" H_2O 4μ	7 cc/min. 73" H_2O 8μ	10 cc/min. 110" H_2O 15μ

Table 2. Spray-on Dopant Process Parameters Utilized in Three Solar Cell Batches. The Dopant Flow Rate was Varied in the Front Surface Coating While all Other Parameters in Both the Front Surface Coating and Back Surface Coating were Held Constant in the Three Batches

FRONT SURFACE COATING-PHOSPHOSILICA DOPANT ($5x10^{19}$)			
	Batch 1	Batch 2	Batch 3
Conveyor Speed	2 ft/min.	2 ft/min.	2 ft/min.
Oven Temperature	$375^{o}F$	$375^{o}F$	$375^{o}F$
Dopant Flow Rate	5 cc/min.	7 cc/min.	10 cc/min.
Drain Spray Nozzle	10 mils	10 mils	10 mils
Atomization Pressure	18 psig	18 psig	25 psig
Drying Time	½ hr.	½ hr.	½ hr.

BACK SURFACE COATING-BOROSILICA DOPANT (10^{20})			
	Batch 1	Batch 2	Batch 3
Conveyor Speed	2 ft/min.	2 ft/min.	2 ft/min.
Oven Temperature	$375^{o}F$	$375^{o}F$	$375^{o}F$
Dopant Flow Rate	7 cc/min.	7 cc/min.	7 cc/min.
Drain Spray Nozzle	10 mils	10 mils	10 mils
Atomization Pressure	18 psig	18 psig	18 psig
Drying Time	½ hr.	½ hr.	½ hr.

Table 3. Electrical Performance of Round and Hexagonal Solar Cells for Three Spray-on Dopant Flow Rates. Data Recorded at 28°C and at 100 mW/cm² Under Tungsten Light. (90 mm cells)

Cell No.	Isc (a)		Voc (v)		Ipp (a)		Vpp (v)		Ppp (w)		FF		η (%)	
	Round	Hex	Round	Hex	Round	Hex	Round	Hex	Round	Hex	Round	Hex	Round	Hex
BATCH 1 (Dopant Flow Rate is 5cc per minute)														
1.	1.76	1.47	.535	.565	1.44	1.31	.390	.420	.562	.550	.597	.662	8.83	10.82
2.	1.78	1.45	.540	.565	1.50	1.13	.375	.440	.562	.497	.585	.607	8.83	9.78
3.	1.78	1.52	.535	.565	1.50	1.34	.330	.430	.495	.581	.520	.677	7.78	11.44
4.	1.82	1.47	.545	.570	1.58	1.28	.375	.425	.592	.544	.597	.662	9.31	10.71
5.	1.71	1.46	.545	.570	1.45	1.34	.375	.400	.544	.536	.584	.644	8.55	10.55
6.	1.68	1.42	.535	.560	1.32	1.12	.375	.425	.495	.476	.551	.599	7.78	9.37
Avg.	1.76	1.47	.539	.566	1.47	1.26	.370	.423	.542	.530	.572	.642	8.51	10.45
BATCH 2 (Dopant Flow Rate is 7 cc per minute)														
1.	1.78	1.49	.545	.570	1.50	1.39	.395	.425	.592	.591	.610	.696	9.31	11.63
2.	1.78	1.53	.545	.555	1.60	1.35	.360	.400	.576	.540	.594	.636	9.05	10.63
3.	1.81	1.48	.545	.570	1.60	1.27	.375	.400	.600	.508	.608	.602	9.43	10.00
Avg.	1.79	1.50	.545	.565	1.56	1.34	.377	.408	.590	.546	.604	.645	9.26	10.75
BATCH 3 (Dopant Flow Rate is 10 cc per minute)														
1.	1.75	1.44	.540	.570	1.49	1.35	.400	.420	.596	.567	.631	.691	9.37	11.16
2.	1.75	1.50	.540	.565	1.37	1.40	.400	.395	.548	.553	.580	.652	8.61	10.89
3.	1.79	1.48	.545	.570	1.59	1.34	.375	.430	.596	.576	.611	.683	9.37	11.34
4.	1.78	1.47	.535	.565	1.45	1.34	.390	.415	.566	.556	.594	.669	8.90	10.95
5.	1.74	1.47	.535	.565	1.35	1.35	.400	.400	.540	.540	.580	.650	8.49	10.63
Avg.	1.762	1.472	.539	.567	1.45	1.35	.393	.412	.569	.558	.600	.669	8.95	11.00

and efficiencies for all three batches were significantly increased after the round solar cells were cut into hexagons. Therefore, it can be concluded that dopant overlap can be eliminated by use of the laserscribe to trim off the solar cell edges.

The laser trimming operation is thus seen to be very effective, and it, or some other edge cleanup technique, is an essential procedure for improving the photovoltaic energy conversion efficiencies of solar cells processed with the spray-on dopant technique.

A relationship between the dopant flow rate and the hexagonal solar cell efficiencies can be established on the basis of the experimental data obtained from the three batches. As shown in Figure 3, a plot was made of the mean value of the hexagonal solar cell efficiencies versus the dopant flow rate. The maximum and minimum efficiencies of each of the three batches are included in the figure. The mean value in the efficiency appears to increase as the dopant flow rate goes up. The increase in efficiency, however, is less than the spread of the data. The data shown in Figure 3 also indicate that the spread in the efficiency data tends to decrease as the dopant flow rate increases. Seven cc/min is indicated as the ideal rate.

B4. <u>Excess Dopant Removal</u>

The excess dopant remaining on spray-on-doped cells following the drive-in process must be removed since the excess dopant will cover the cell surface in the form of a silica film and have the undesirable effect of reducing the solar cell electrical performance. This film can be removed by a hydrofluoric acid etching process. The electrical performances of solar cells with and without excess dopant removal are shown in Figure 4 and Table 4. The electrical

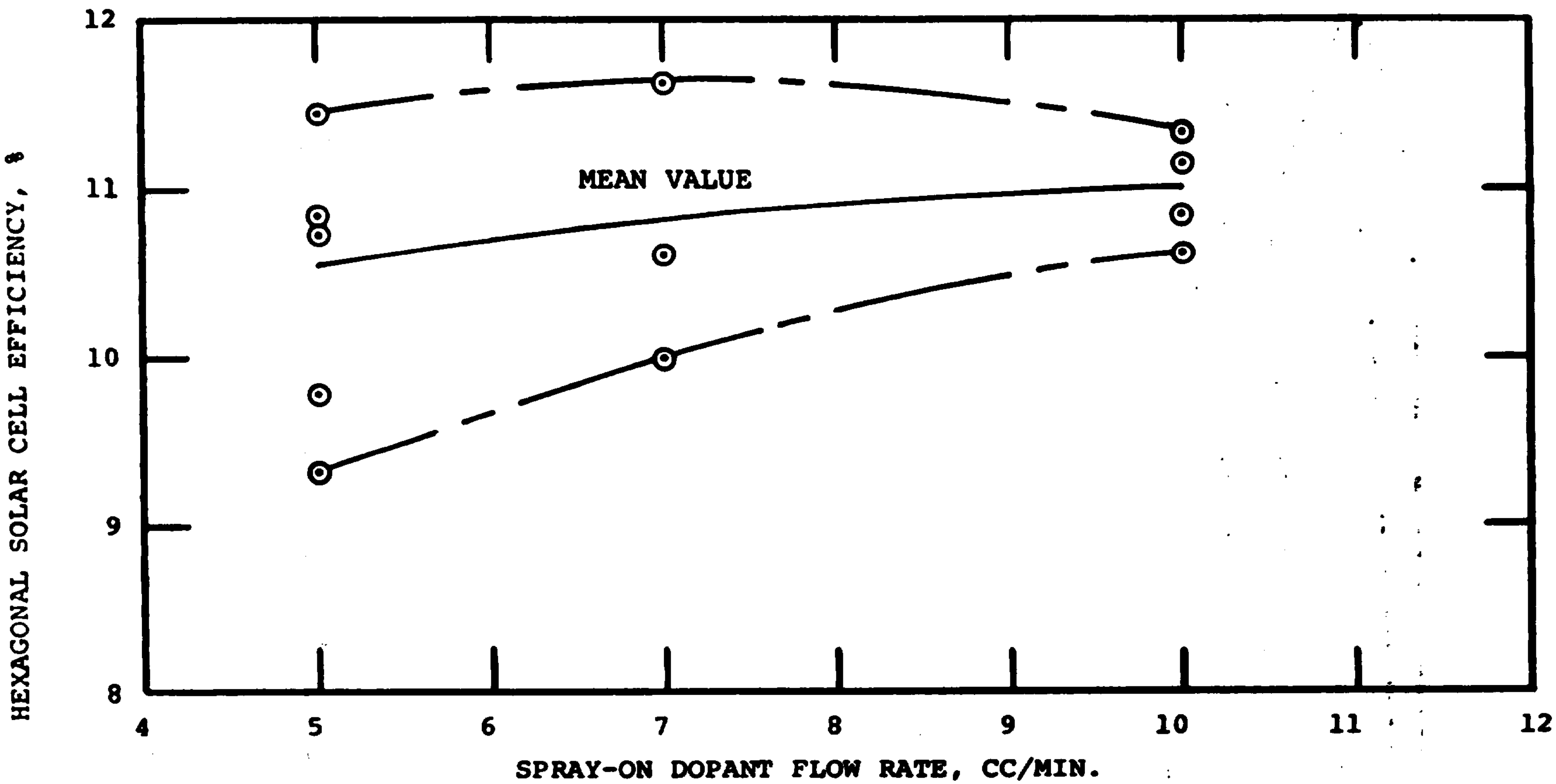


Figure 3. Spray-on Dopant Flow Rate Versus Hexagonal Solar Cell Efficiency.

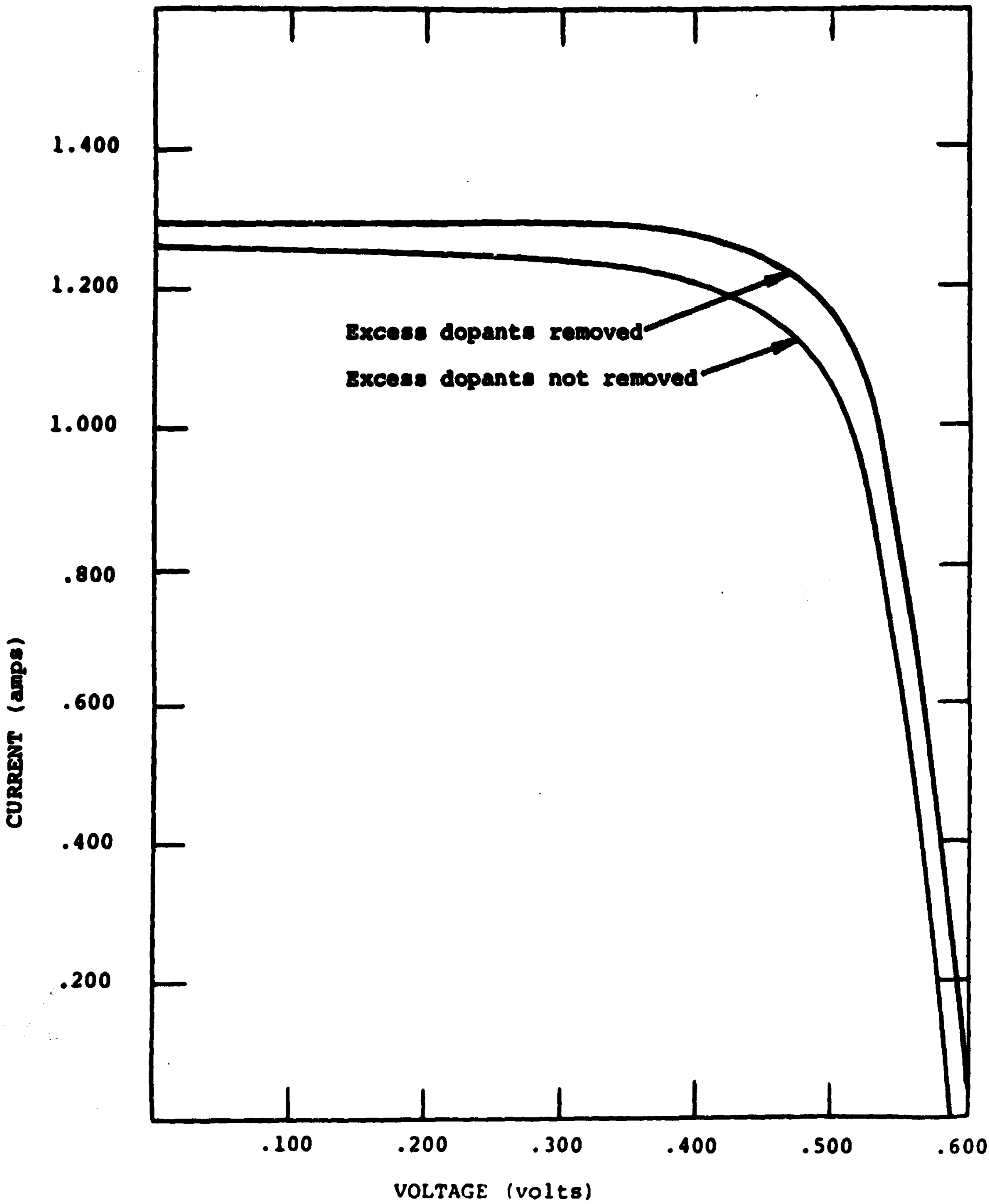


Figure 4. Effect on Solar Cell Electrical Performance when Excess Dopants are Removed in the Spray-on Dopant Process. Cells are Texturized with no AR Coating. Surface Area is 45 cm^2. Cells are Tested at 28°C under 100 mW/cm^2 Tungsten Light. (10 cells)

Table 4. Electrical Parameters of Solar Cells With and Without Excess Dopant Removal. (10 cells)

	EXCESS DOPANTS NOT REMOVED	EXCESS DOPANTS REMOVED
I_{sc}	1.25 amps	1.28 amps
V_{oc}	0.6 volts	0.61 volts
I_{pp}	0.10 amps	1.18 amps
V_{pp}	0.475 volts	0.480 volts
P_{max}	0.5225 watts	0.5664 watts
FF	0.697	0.725
η	11.611%	12.59%

performance improvement includes both the fill factor and the solar cell efficiency. It is apparent from the figure and table that excess dopant removal significantly enhances solar cell efficiency.

B5. Polymer Dopant for Back Surface Field Formation

It has been well documented in the literature that the inclusion of an effective back surface field within the solar cell structure enhances open circuit voltage and short circuit current. Back surface field formation with spray-on boron dopant has been investigated as an alternative, low-cost back surface field formation technique.

Spray-on boron back surface fields were demonstrated in earlier work. The main objective of this work was to assess the degree to which drive-in temperature variations influence the effectiveness of spray-on boron back surface fields.

Three batch tests were performed. All parameters were identical in each case, with the exception of the spray-on boron drive-in temperature. The set of processing steps utilized for each case followed the baseline fabrication sequence shown in Figure 5, with spray-on phosphorous, spray-on boron, and SiO AR coating. The I-V curves for Batches P-10 (1100^{o}C), P-11 (1050^{o}C), and P-12 (1000^{o}C) are presented in Figures 6, 7 and 8, respectively.

It is clear from Table 5 that Batch P-12 (1000^{o}C) has the highest average efficiency and fill factor of the three batches. In addition, Batch P-12 manifests the highest average short circuit current and open circuit voltage of the three batches.

Since enhanced open circuit voltage and short circuit current are characteristics of an effective back surface field, it appears that a drive-in temperature of 1000^{o}C is best for spray-on boron back surface fields (among those tested).

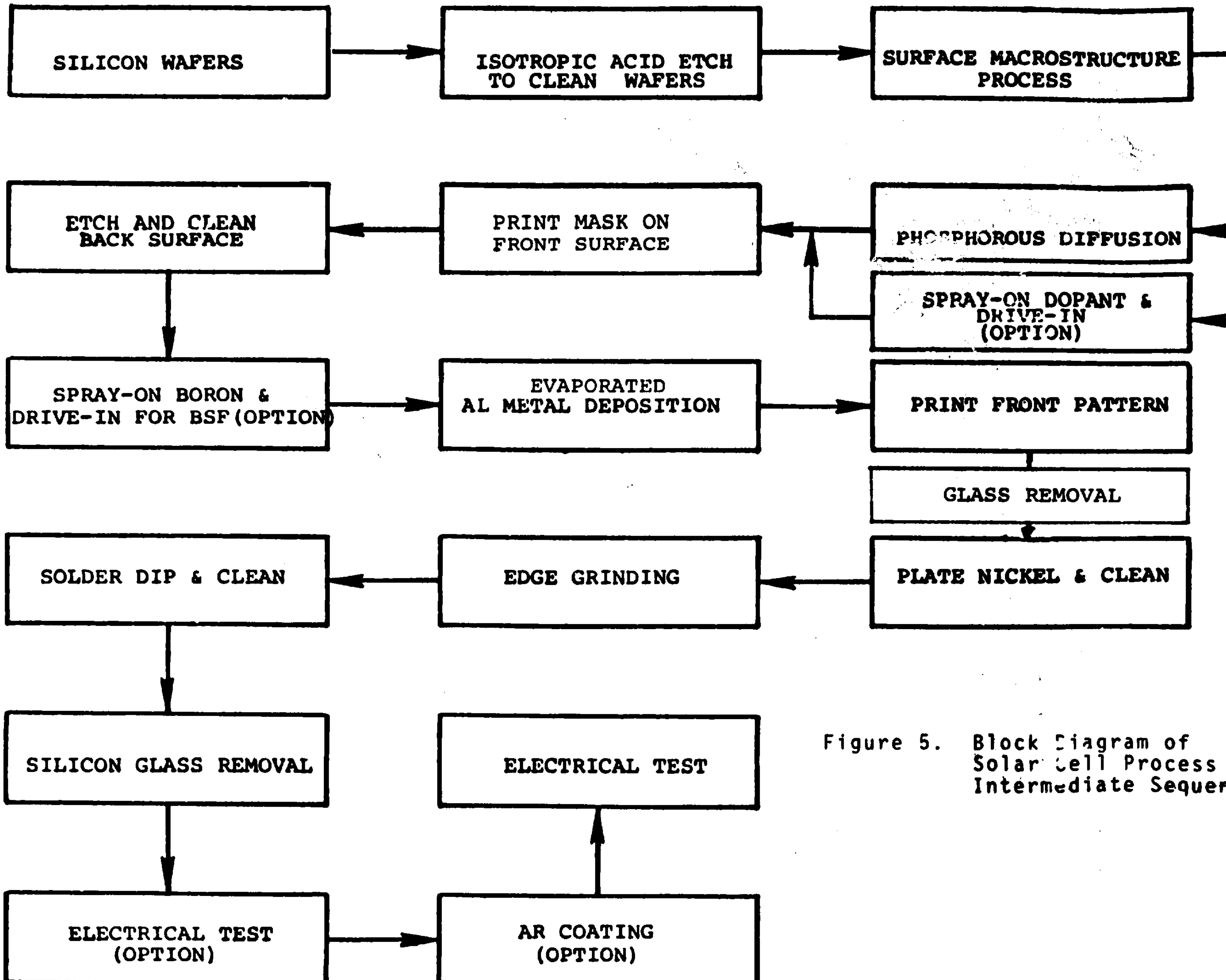


Figure 5. Block Diagram of Solar Cell Process Intermediate Sequence

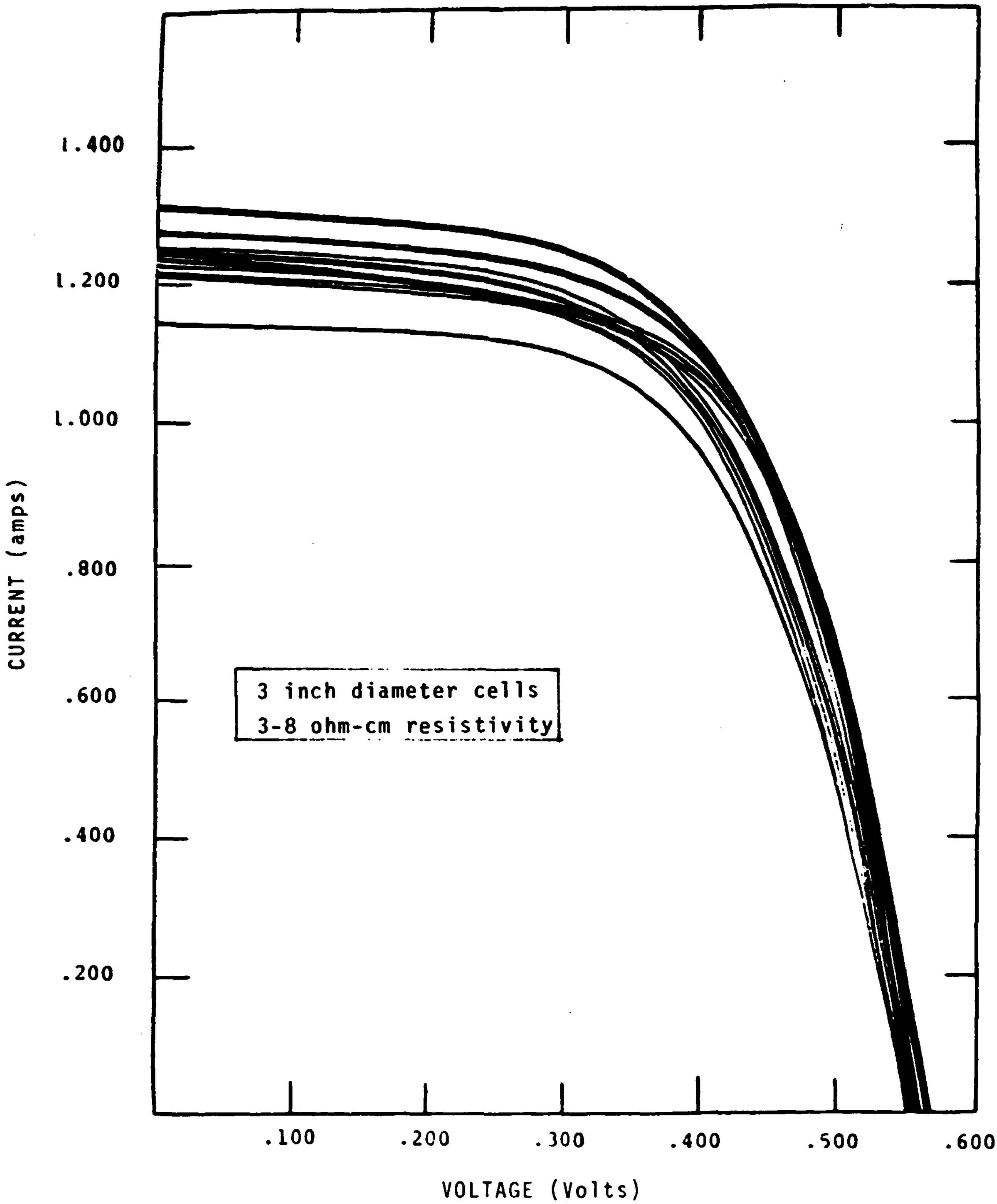


Figure 6. Electrical Performance Curves for Solar Cells Spray-on Doped with Boron and Driven-in at 1100°C for 25 Minutes. The Cells were Tested under Tungsten Light at 100 mW/cm^2 and at 28°C.

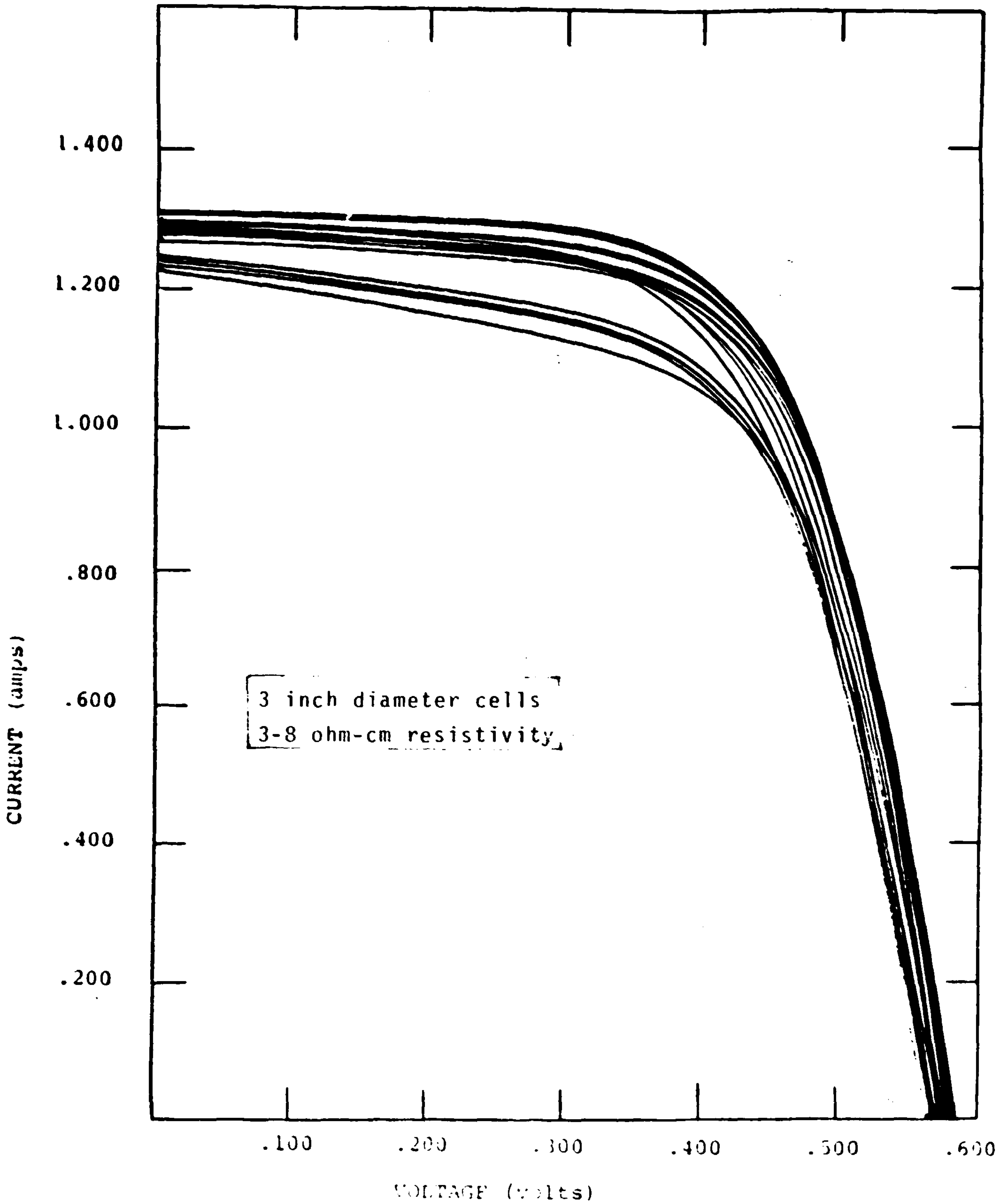


Figure 7. Electrical Performance Curves for Solar Cells Spray-on Doped with Boron and Driven-in at 1050°C for 25 minutes. The Cells were Tested Under Tungsten Light at 100 mW/cm^2 and at 28°C.

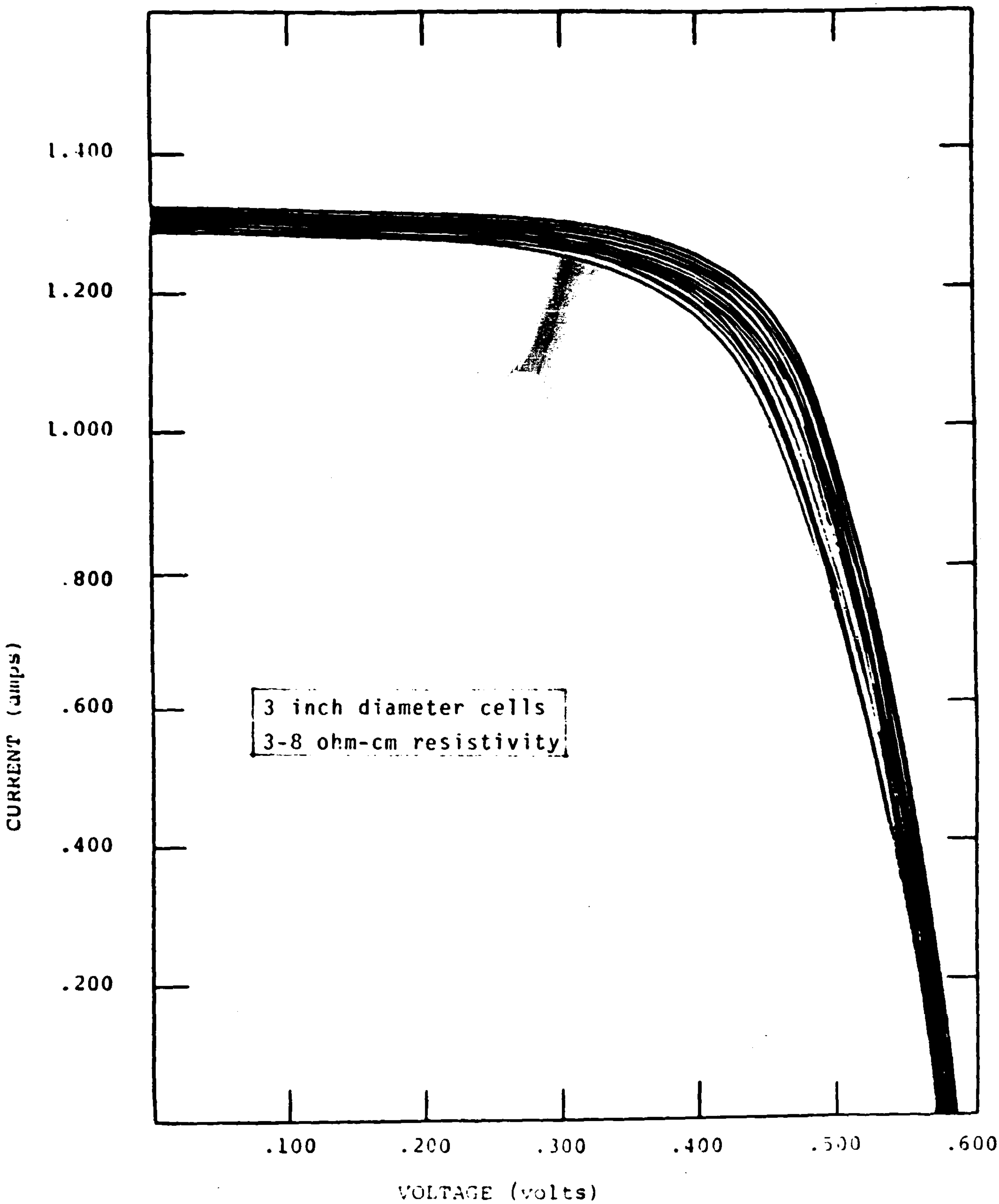


Figure 8. Electrical Performance Curves for Solar Cells Spray-on Doped with Boron and Driven-in at 1000°C for 25 Minutes. The Cells were Tested Under Tungsten Light at 100 mW/cm^2 at 28°C.

Table 5. Electrical Performance Data for Solar Cells Spray-on Doped with Boron and Driven-in at Three Different Temperatures. Active Area of the Solar Cells is 41.43 cm^2. The Cells were Tested Under Tungsten Light at 100 mW/cm^2 and at 28^oC. (15 Samples/Group)

BATCH	Isc	Voc	Ipp	Vpp	η(%)	FF	$\frac{\Delta\eta}{\eta}$ (%)	$\frac{\Delta FF}{FF}$ (%
P-10: Boron drive-in temperature was 1100°C for 25 minutes.								
High	1.31	.565	1.14	.390	10.73	.601	+6.87	-2.28
Low	1.14	.545	1.01	.380	9.26	.618	-7.77	+0.48
Wt.Ave.	1.23	.55	1.08	.385	10.04	.615		
P-11: Boron drive-in temperature was 1050°C for 25 minutes.								
High	1.31	.580	1.18	.420	11.96	.652	+6.31	+1.40
Low	1.22	.565	1.01	.425	10.36	.623	-7.91	-3.11
Wt.Ave.	1.26	.575	1.11	.420	11.25	.643		
P-12: Boron drive-in temperature was 1000°C for 25 minutes.								
High	1.32	.585	1.18	.445	12.67	.680	+4.71	+2.56
Low	1.28	.570	1.12	.415	11.22	.637	-7.27	-3.92
Wt.Ave.	1.30	.580	1.15	.435	12.10	.663		

A SAMICS cost analysis was performed on the spray-on dopant process sequence. A detailed cost breakdown for the spray-on dopant process is shown in Table 6. The process sequence consists of three steps which include (1) spray-on N^+ and P^+ dopants, (2) dopant drive-in, and (3) excess dopant removal. The resulting process cost is 4.34 cents per peak watt in 1980 cents. This cost is in-line with the 1986 LSA program goals. Consequently, the spray-on dopant process is highly recommended for usage in the 1986 LSA solar cell industry.

C. Aluminum Spray-on Metallization Study

A low cost spray-on technique for applying aluminum to the back surface of solar cells was investigated. Preliminary experimentation in this area involved spraying a binder solution onto the silicon wafer back surface, followed by spraying powdered aluminum. The aluminum oxide particles produced by rapid oxidation of powdered aluminum in the spray-on system exploded.

To avoid this situation in subsequent experiments, aluminum slurry was used in place of the powdered aluminum. Two aluminum slurry spray-on methods were formulated to demonstrate the feasibility of the spray-on aluminum technique. The first method involves the use of a proximity sprayer which simultaneously sprays both an aluminum slurry and a binder solution through separate nozzles. Initial experiments resulted in uniformity problems and thus this method was discontinued. The second technique considered utilizes an aluminum/binder slurry which is sprayed through one nozzle.

The existing spray-on system at Photowatt International required several equipment modifications in order to perform the necessary experiments. These equipment modifications included the addition of a metallizing spray booth

Table 6. Process Costs for a Fully Automated Spray-on Dopant Junction Formation Process in 1980 Cents per Peak Watt.

EQUIPMENT		0.770
FLOOR SPACE		0.244
LABOR		0.744
MATERIAL		1.652
UTILITY		0.897
	TOTAL	4.357

SPRAY-ON DOPANT PROCESS STEPS

1. Spray-on N^+ and P^+ Dopants
2. Dopant Drive-in
3. Excess Dopant Removal

located ahead of the present spray chamber, and an extension of the conveyor. An illustration of the modified spray-on system is depicted in Figure 9. The operation of this system requires manual removal of the pallet from the present booth where the binder solution is applied, and subsequent placement of the pallet ahead of the new booth where the metal is applied. Advanced Concepts Corporation of Bristol, Rhode Island performed all of the above modifications.

Two batches of 25 wafers each were sent to Advanced Concepts after $POCl_3$ diffusion for the performance of initial spray-on aluminum p^+ back surface field experiments. Batch L-1100 consisted of 2.15" diameter silicon wafers with base resistivities of ~3-8 ohm-cm and Batch L-1101 consisted of 3" diameter silicon wafers with base resistivities of ~10-20 ohm-cm. The initial processing steps used in both batch tests were as follows:

1. Spray-on aluminum slurry.
2. Sinter at 875^{o}C for 120 seconds in 5% hydrogen forming gas.

The front surfaces of the silicon wafers returned from Advanced Concepts Corporation showed evidence of sporadic contamination with aluminum. To remove all traces of aluminum from the front surfaces, the wafers in both batches were subjected to cleaning in a 10% HF solution for four minutes. Subsequently, this step has been incorporated into the standard process. After the completion of this cleaning step, both batches were processed with the remaining steps of Photowatt's standard solar cell processing sequence (Refer to Figure 12).

The I-V curves of Batches L-1100 and L-1101 are shown in Figures 10 and 11, respectively. A summary of the electrical performance data of both batch tests is presented in Table 7. The open circuit voltage in high resistivity Batch L-1101 (0.590 - 0.605 volts) are higher than the open circuit voltages in low resistivity Batch L-1100 (0.570 - 0.575 volts).

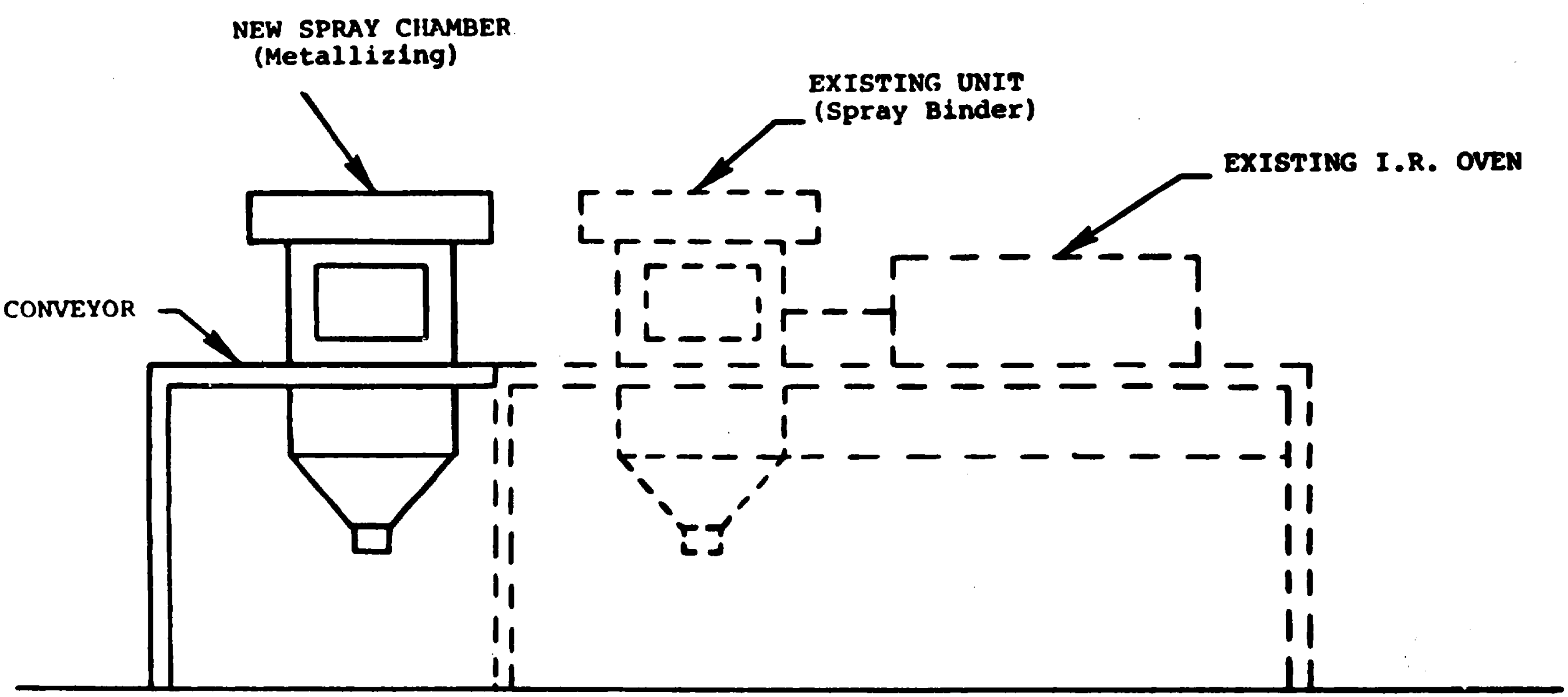


Figure 9. Illustration of the Modified Spray-on System for Applying Aluminum to the Back Surfaces of Solar Cells.

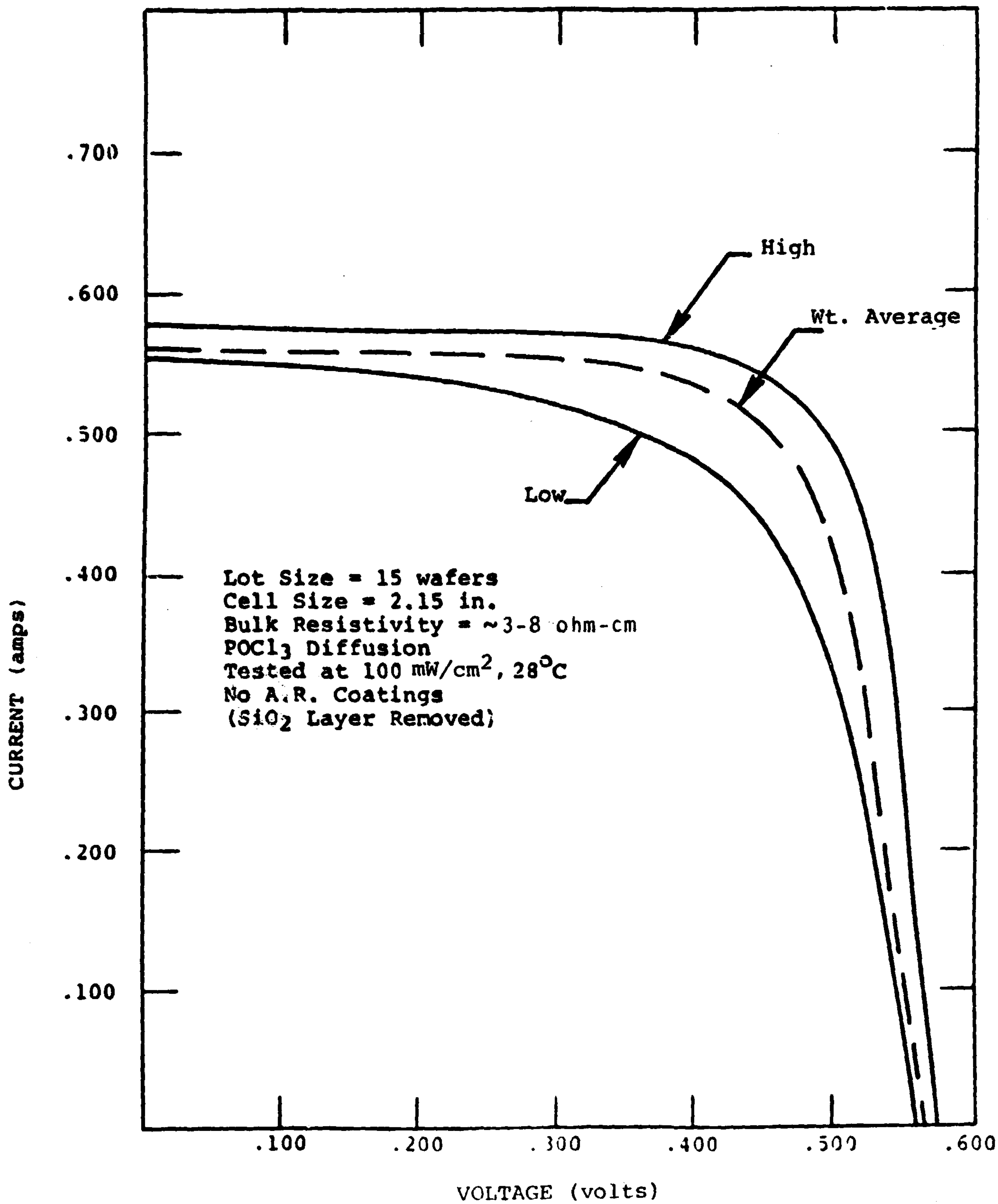


Figure 10. Electrical Performance of Batch L-1100 with Spray-on Aluminum p^+ BSF.

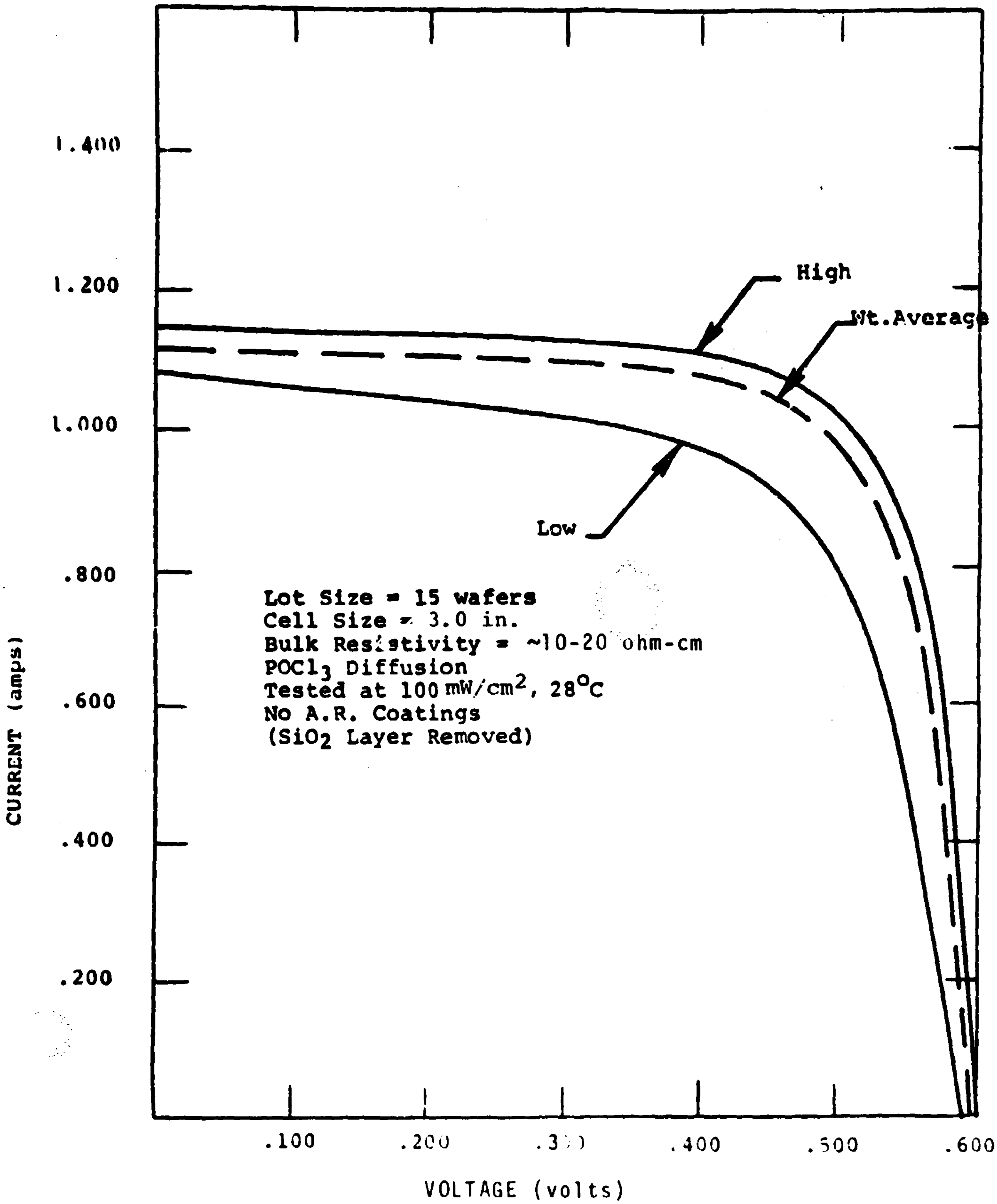


Figure 11. Electrical Performance of Batch L-1101 with Spray-on Aluminum p^+ BSF.

Table 7. Electrical Characteristics of Batch Tests Processed with Spray-on Aluminum p^+ Back Surface Field.

Batch	I_{SC} (A)	V_{oc} (V)	I_{pp} (a)	V_{pp} (v)	η (%)	FF	$\frac{\Delta\eta}{\eta}$ %	$\frac{\Delta FF}{FF}$ %
Batch L-1100: ~3-8 ohm-cm., 2.15" diameter silicon wafers.								
High	.580	.575	.515	.480	10.55	.741	9.1	6.31
Low	.562	.565	.465	.420	8.34	.615	-13.75	-11.76
Wt.Ave.	.570	.570	.515	.440	9.67	.697		
Batch L-1101: ~10-20 ohm-cm., 3" diameter silicon wafers.								
High	1.13	.605	1.01	.503	11.14	.743	3.63	0.95
Low	1.08	.590	.87	.455	8.68	.621	-19.26	-15.63
Wt.Ave.	1.11	.600	.99	.495	10.75	.736		

The work performed has shown the spray-on technique to be a viable method of applying aluminum to the back surfaces of solar cells.

D. Spray-on Antireflective Coating Study

D1. Background

The development of low cost, efficient solar cells is facilitated by the use of a low-cost technique for applying antireflective (AR) coatings. One promising method involves spraying on the required antireflective coatings. To ensure the success of this method, the spray-on system must be capable of consistently spraying the AR coating to a designated thickness. Although exact theoretical computations of the AR coating thickness can be made, for our purposes a number of simplifying assumptions was made in order to obtain an approximate value for the thickness which leads to minimal reflection losses. These assumptions include: (a) normal incident light on a flat wafer surface, (b) monochromatic incident light, and (c) no absorption loss in the AR coating layer. A discussion of the procedure used to compute the AR coating layer thickness which minimizes reflection losses is presented below.

For a single layer AR coating at a single wavelength, λ, the reflectance, R, is given by the following expression.

$$R = \left(\frac{(n_0 - n) \cos k_1 l_1 - i \left| (nn_0/n_1) - n_1 \right| \sin K_1 l_1}{(n_0 + n) \cos k_1 l_1 - i \left| n_1 + (nn_0/n_1) \right| \sin k_1 l_1} \right)^2 \quad \text{(Eq. 1)}$$

n_0 = refractive index of the incident medium
n = refractive index of the transmitting medium
n_1 = refractive index of the AR coating
k_1 = $2\pi n_1/\lambda$
l_1 = thickness of AR coating
i = $(-1)^{1/2}$

If the optical thickness of the AR coating $n_1 l_1$ is a quarter wavelength, then $k_1 l_1 = \pi/2$ and the reflectance for a quarter wavelength film becomes:

$$R = \left(\frac{nn_o - n_1^2}{nn_o + n_1^2} \right)^2 \qquad \text{(Eq. 2)}$$

It is clear that the reflectance is zero if $n_1 = (nn_o)^{1/2}$ for $l_1 n_1 = \lambda/4$.

The antireflective coating, which was studied during this contract was Titaniumsilica "C". The thickness of Titaniumsilica "C" AR coating with refractive index, n_1, equal to 1.95 that minimizes reflection losses was computed as follows:

$$l_1 = \frac{\lambda}{4n_1} = \frac{6000\text{Å}}{4(1.95)} = 769\text{Å} \qquad \text{(Eq. 3)}$$

This thickness corresponds to a quarter wavelength for photons near the middle of the usable solar spectrum, (6000Å). The reflection loss at this thickness was computed with the aid of Equation 2. The reflection loss amounts to 0.064%, for this case. If an AR coating with a refractive index of 2.0 had been used instead of Titaniumsilica "C", the reflective loss would be zero.

D2. <u>AR Coating Thickness Experiments with Polished Wafers</u>

Initial experimentation in the area of spray-on AR coatings focussed on achieving a Titaniumsilica "C" AR coating layer thickness approaching the values of 769Å. Several preliminary test runs indicated that the spray-on system was not capable of achieving Titaniumsilica "C" AR coating layer thicknesses of less than 1000Å because of the viscosity of the mixture and the 25" H_2O pressure limit. Nevertheless, two batch tests were performed to determine the viability of the spray-on AR coating technique.

Both solar cell batches were processed with the fabrication sequence shown in Figure 5. Following SiO_2 removal in each case, the electrical performances of the solar cells were measured. Titaniumsilica "C" AR coating was then sprayed onto Batch T-100 to a thickness of 1500Å, and sprayed onto Batch T-101 to a thickness of 1000Å. (Both determined by color.) The electrical performances of both batch tests were then measured.

Upon comparison of the electrical performance results before and after the spray-on AR coating application in Tables 8a & 8b, it can be seen that the average short circuit current and average efficiency improved 11.8% and 10.18% for Batch T-100 (1500Å), and 13% and 10.8% for Batch T-101 (1000Å). Clearly, the smaller AR coating layer thickness (1000Å) led to the larger improvements in average short circuit current and average efficiency.

Good AR coating thickness uniformity over polished silicon wafer surfaces was obtained by properly adjusting spray-on equipment parameters. To determine whether the spray-on AR coating technique can be performed successfully on partially texturized and full texturized silicon wafer surfaces, Photowatt performed several experiments. All experiments utilized the RCA titanium (IV) isopropoxide formulation AR coating whose composition is shown in Table 9.

D3. Experiments with Partially Texturized Wafers

A batch of 3" diameter silicon wafers was processed using the fabrication sequence shown in Figure 12. Following SiO_2 glass removal in HF, the electrical performances of the solar cells were measured. The spray-on AR coating process was then performed on these cells. The uniform blue color over the entire surface area of the coated cells indicated good AR coating uniformity.

Table 8a. Solar Cell Electrical Performance Versus Coating Thickness for Spray-on Titaniumsilica "C". (3" Diameter Cells, 3-8 Ω-cm)

BATCH	I_{SC} (a)	V_{OC} (v)	I_{PP} (a)	V_{PP} (v)	η (%)	FF
T-100 No A.R. coating (SiO_2 removed).						
1	1.12	.570	1.03	.425	10.57	.686
2	1.125	.569	1.02	.450	11.087	.717
3	1.06	.570	.92	.435	9.667	.662
4	1.14	.565	1.05	.425	10.779	.693
5	1.11	.570	.97	.425	9.958	.652
Ave.	1.11	.569	1.00	.432	10.41	.682

BATCH	I_{SC} (a)	V_{OC} (v)	I_{PP} (a)	V_{PP} (v)	η (%)	FF
T-101 No A.R. coating (SiO_2 removed).						
1	1.12	.565	1.01	.445	10.856	.71
2	1.13	.570	.98	.450	10.648	.685
3	1.13	.575	.95	.450	10.32	.658
4	1.16	.565	1.02	.440	10.83	.685
Ave.	1.135	.569	.99	.446	10.66	.685

Table 8b. Solar Cell Electrical Performance Versus Coating Thickness for Spray-on Titaniumsilica "C".
(3" Diameter Cells, 3-8 Ω-cm)

BATCH	I_{SC} (a)	V_{OC} (v)	I_{PP} (a)	V_{PP} (v)	η (%)	FF
T-100 Titaniumsilica "C" A.R. coating, 1500Å thickness.						
1	1.25	.570	1.14	.430	11.84	.688
2	1.19	.573	1.10	.443	11.77	.715
3	1.23	.575	1.01	.430	10.49	.614
4	1.29	.570	1.16	.430	12.04	.678
5	1.25	.570	1.08	.430	11.23	.652
Ave.	1.24	.572	1.10	.433	11.47	.669

BATCH	I_{SC} (a)	V_{OC} (v)	I_{PP} (a)	V_{PP} (v)	η (%)	FF
T-101 Titaniumsilica "C" A.R. coating 1000Å thickness.						
1	1.25	.570	1.10	.430	11.425	.664
2	1.29	.575	1.12	.450	12.17	.679
3	1.29	.575	1.10	.440	11.68	.653
4	1.30	.570	1.14	.435	11.97	.669
Ave.	1.28	.573	1.115	.439	11.81	.666

Table 9. Composition of AR Coating Spray Source Solution for RCA I TiO_2.

COMPONENT	VOL.	% (ν/ν)	FUNCTION
Titanium (IV) Isopropoxide, Ti $(OCH(CH_3)_2)_4$	1	8.3	TiO_2 Source
n-Butyl Acetate, $CH_3CO_2(CH_2)_3CH_3$	3	25	Diluent/Solvent
2-Ethyl-1-Hexanol, $CH_3(CH_2)_3CH(C_2H_5)CH_2OH$	4	33	Sprayability Agent
Isopropanol, Anhydrous, $(CH_3)_2CHOH$	4	33	Leveling Agent

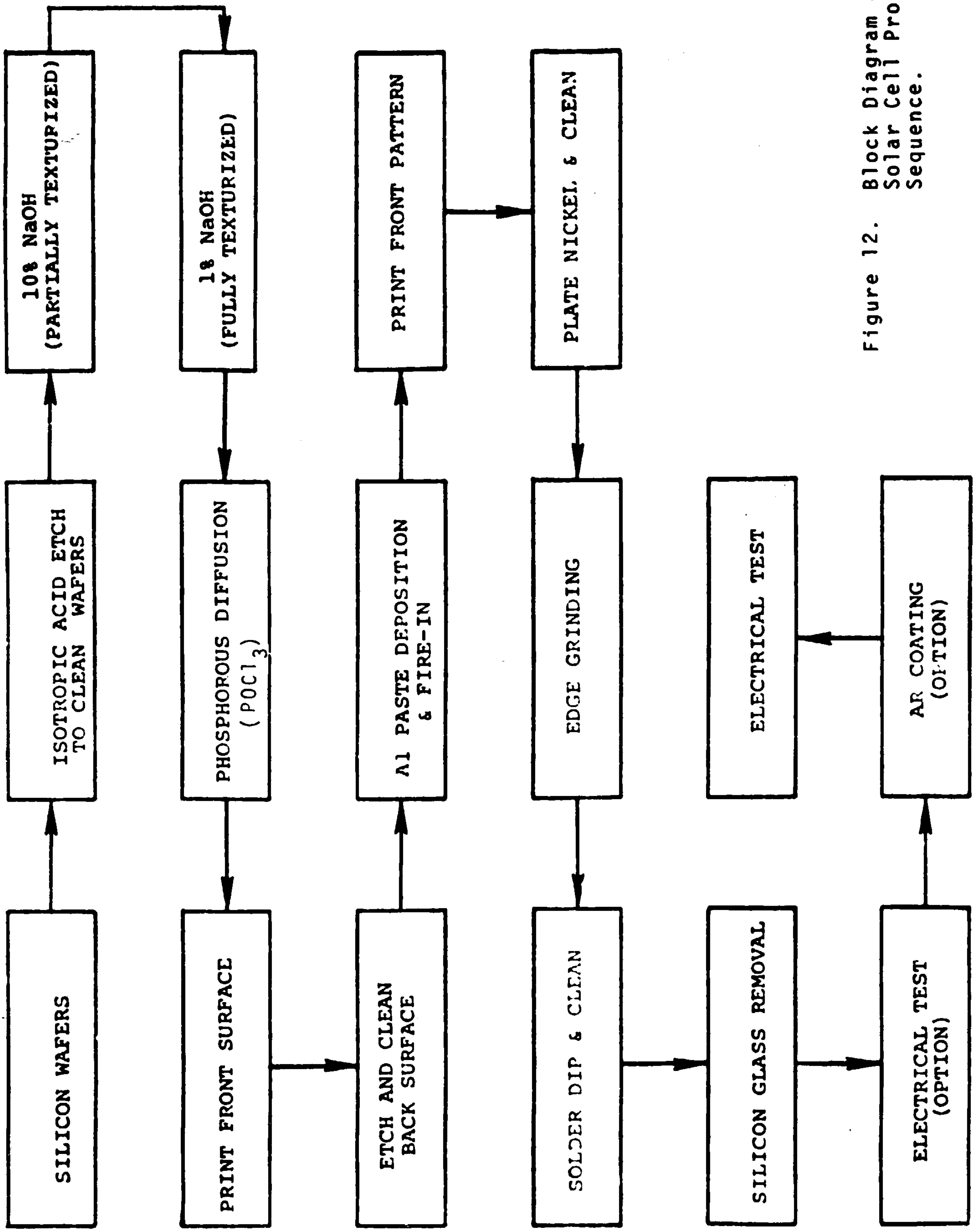


Figure 12. Block Diagram of Solar Cell Process Sequence.

The electrical performances of the AR coated cells were measured and compared to the electrical performances of the same cells without an AR coating. For identification purposes, the cells tested after SiO_2 removal are labelled as Batch A-1120, and the same cells emerging from the spray-on AR coating process are labeled as Batch A-1121.

The electrical performance results for both batches are presented in Figures 13 and 14. A summary of the electrical performance data of both batches is presented in Table 10. The average efficiency and short circuit current of Batch A-1121 (AR coated) improved 29.22% and 29.67%, respectively, relative to Batch A-1120 (no AR coating). The average short circuit current and efficiency improvements indicated by these data demonstrate that RCA I TiO_2 spray-on AR coating can be used successfully on partially texturized silicon wafers.

D4. Experiments with Fully Texturized Wafers

A lot of 20 3" diameter, silicon wafers was processed using the fabrication sequence shown in Figure 12. Following SiO_2 removal in HF, the electrical performances of the fully texturized solar cells were measured. The spray-on AR coating process was then performed on these cells with RCA I TiO_2 AR coating.

Initial attempts on fully texturized wafer surfaces were unsuccessful. Uniform coating thicknesses could not be maintained, despite repeated attempts at spray-on equipment parameter adjustments. To remedy this situation, several process modifications were explored.

The first process modification involved heating the wafer prior to the spray-on AR coating application. Ideally, this procedure would volatilize the AR coating to prevent excessive flow into the space between neighboring pyramids. This procedure was shown to be untenable when the heated wafers cooled considerably during transport by conveyor to the spray-on system.

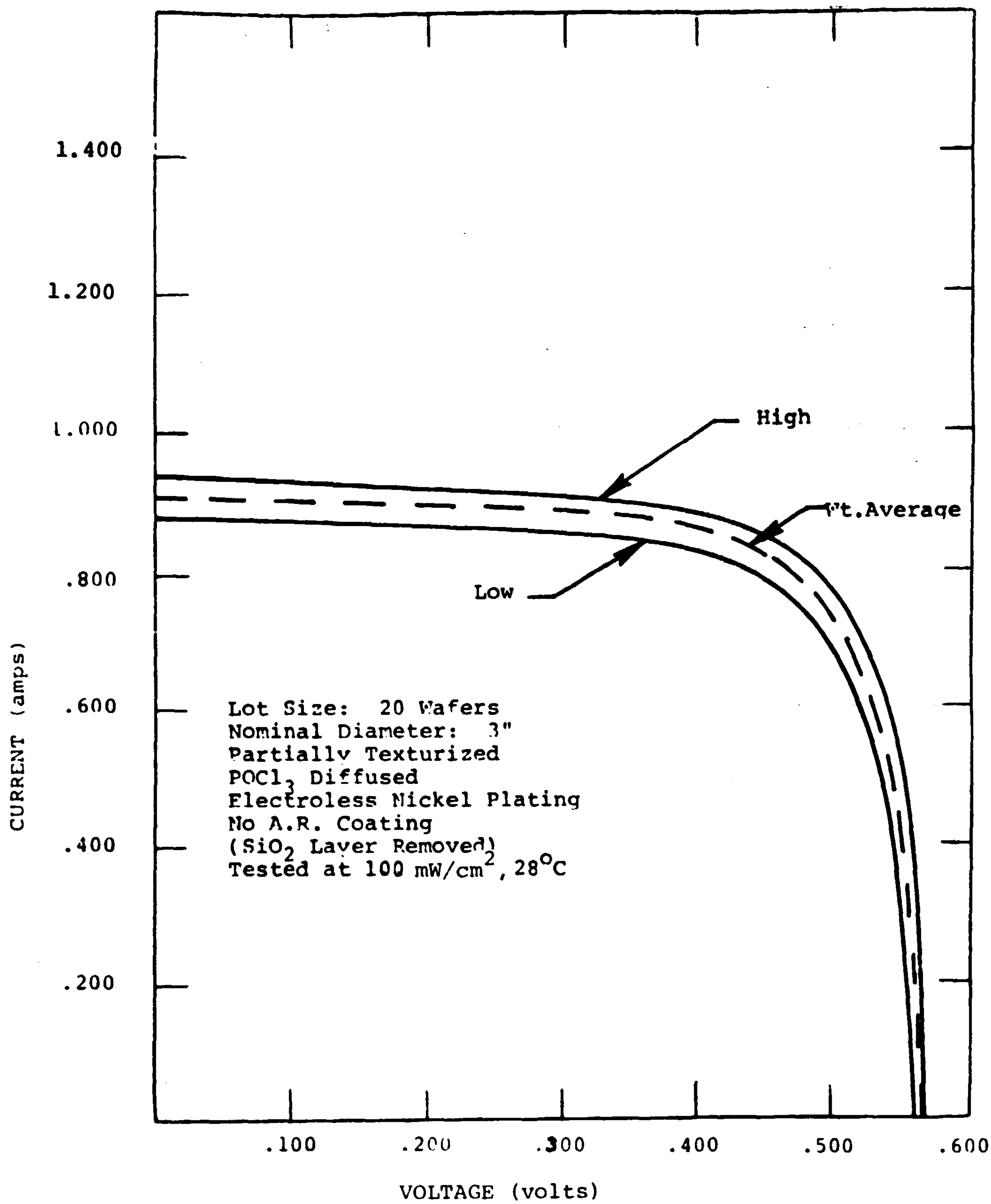


Figure 13. Electrical Performance of Batch A-1120, Tested after SiO_2 Removal.

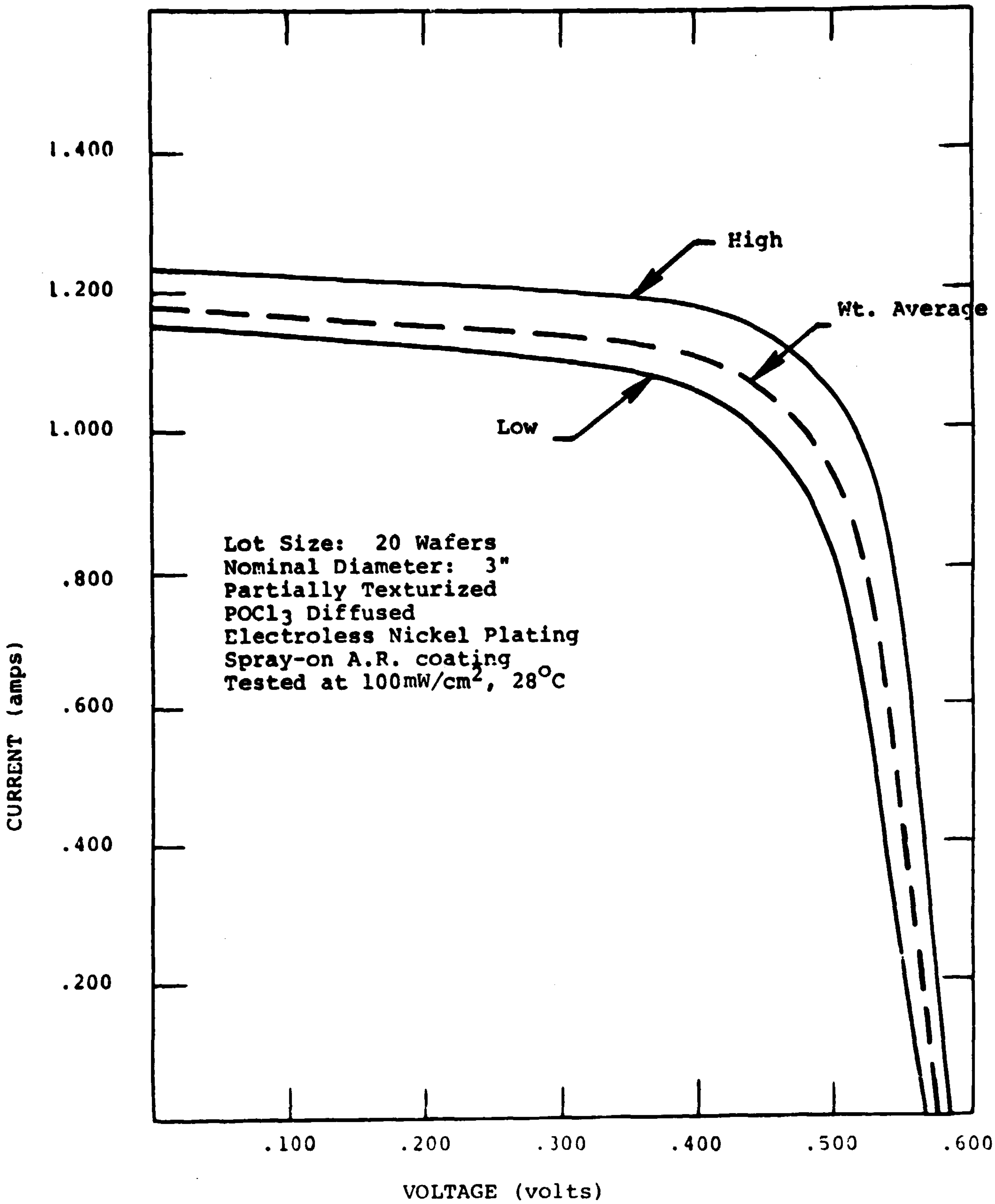


Figure 14. Electrical Performance of Batch A-1121, with Spray-on AR Coating.

Table 10. Summary of Electrical Performance Data for Batches A-1120 and A-1121

Batch	I_{sc} (a)	V_{oc} (v)	I_{pp} (a)	V_{pp} (v)	η (%)	FF	$\frac{\Delta\eta}{\eta}$ (%)	$\frac{\Delta FF}{FF}$ (%)
Batch A-1120 Partially texturized, SiO_2 glass removed, no A.R. coating.								
High	.94	.565	.84	.462	9.43	.73	3.97	0
Low	.88	.560	.82	.415	8.27	.69	-8.82	-5.50
Wt.Ave.	.91	.565	.82	.455	9.07	.73		
Batch A-1121 Partially texturized, spray-on A.R. coating. (1000Å)								
High	1.23	.580	1.12	.470	12.79	.74	9.13	4.23
Low	1.15	.565	1.04	.420	10.61	.67	-9.47	-5.63
Wt.Ave.	1.18	.575	1.06	.455	11.72	.71		

The second procedure involved spraying a wetability agent (2-ethyl-1-hexanol) onto the wafer surface prior to the spray-on AR coating application. Although the solar cells initially emerging from this process did show evidence of a slight improvement in coating uniformity, these results were not, for the most part, reproducible. This same procedure was repeated with the wafers being manually dipped into the wetability agent, prior to the spray-on AR coating application. They emerged from this process exhibiting the blue color characteristic of a uniform AR coating thickness.

The electrical performances of the AR coated, fully texturized cells were measured and compared to the electrical performances of the same cells without an AR coating. For identification purposes, the cells tested after SiO_2 removal are labeled as Batch A-1122, and the same cells emerging from the spray-on AR coating process are labeled as Batch A-1123. The I-V curves of Batches A-1122 and A-1123 are presented in Figures 15 and 16, respectively. A summary of the electrical performance data from both batch tests is presented in Table 11. The average efficiency and short circuit current of Batch A-1123 (AR coated) improved 10.20% and 10.00%, respectively, relative to Batch A-1122 (no AR coating).

In view of these results, it can be concluded that fully texturized wafers will be uniformly coated with spray-on RCA I TiO_2 AR coating, if the process modification discussed above is utilized.

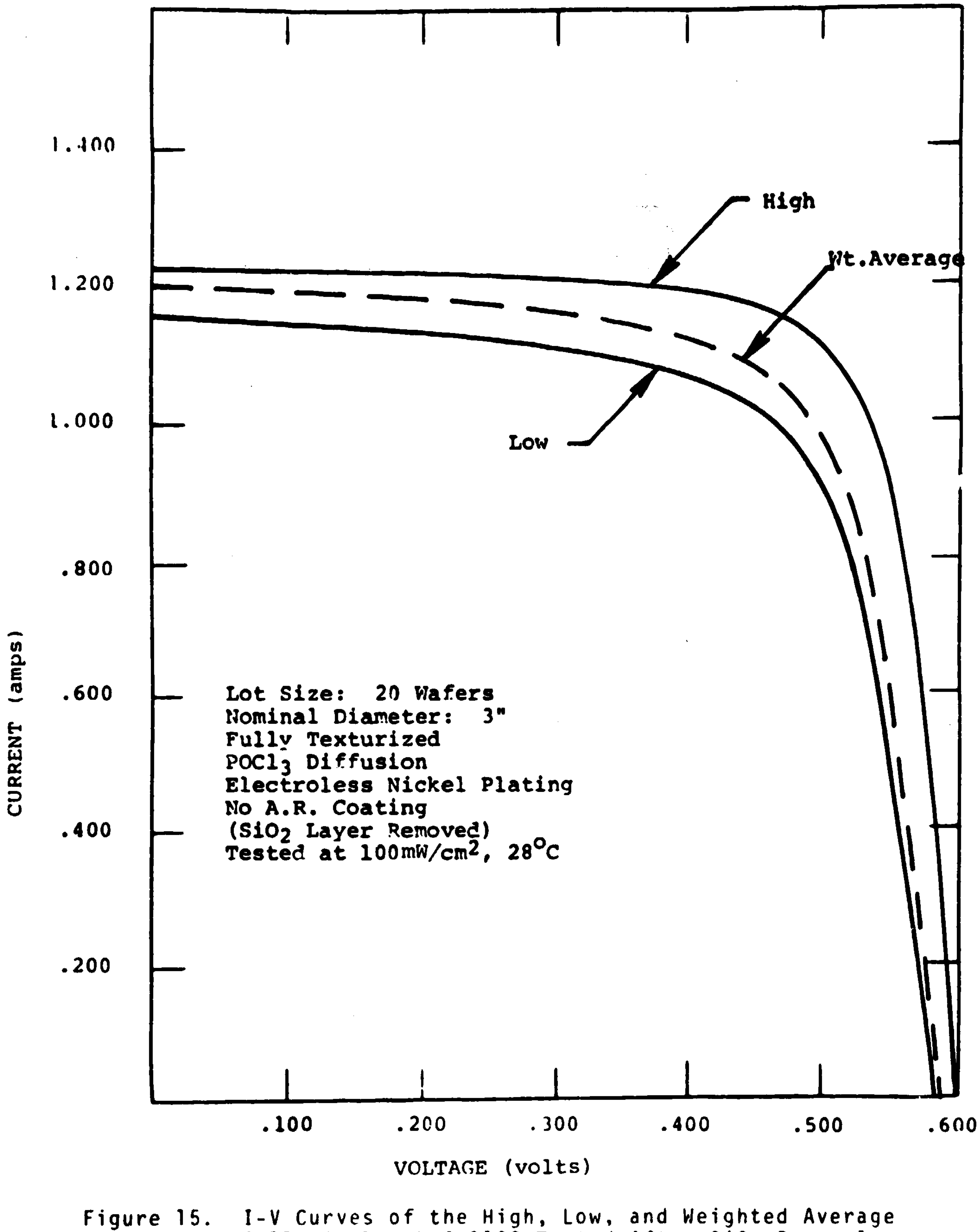


Figure 15. I-V Curves of the High, Low, and Weighted Average Cells in Batch A-1122 Tested After SiO_2 Removal.

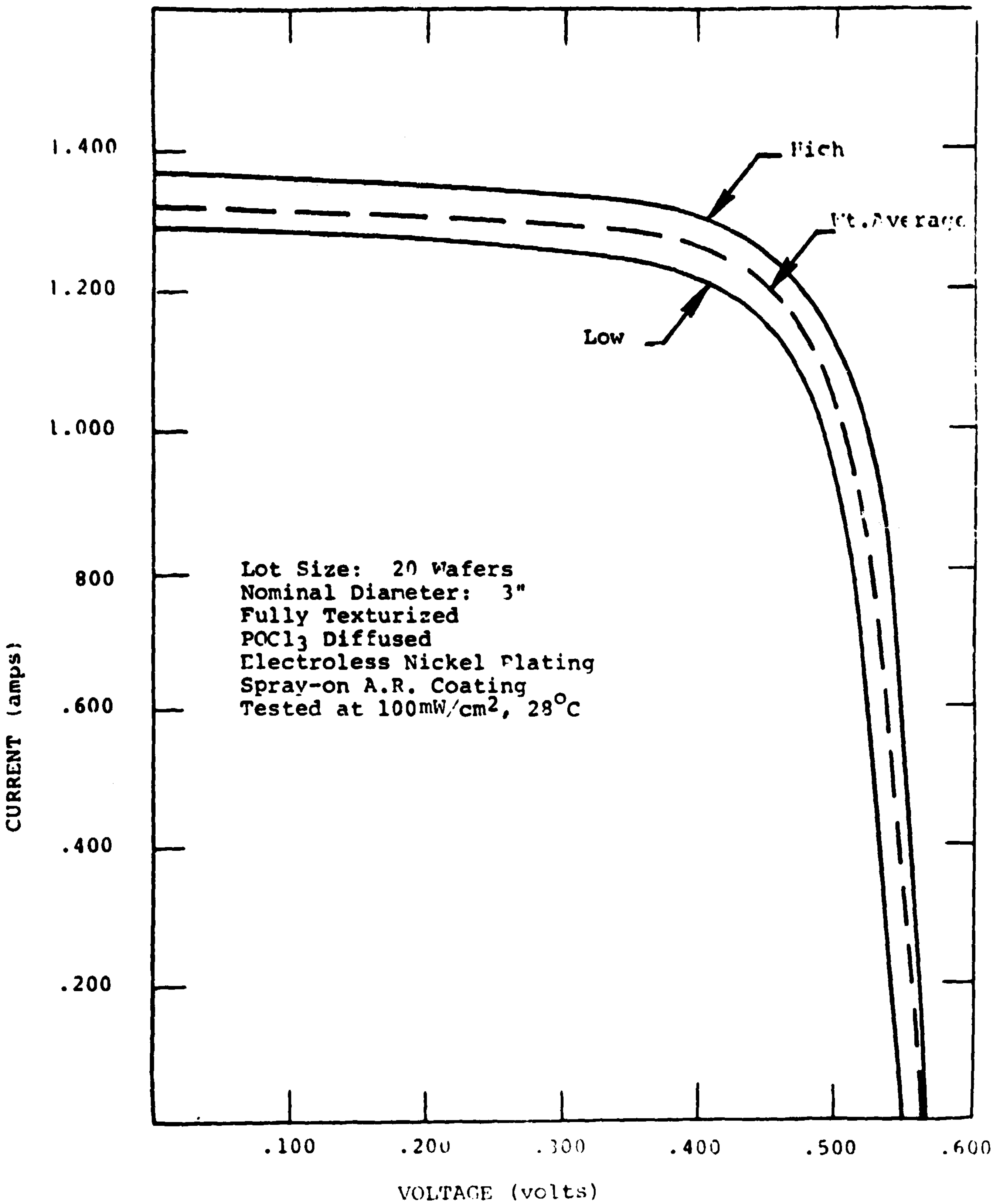


Figure 16. I-V Curves of the High, Low, and Weighted Average Cells in Batch A-1123 with Spray-on AR Coating.

Table 11. Summary of Electrical Performance Data for Batches A-1122 and A-1123

Batch	I_{sc} (a)	V_{oc} (v)	I_{pp} (a)	V_{pp} (v)	η (%)	FF	$\frac{\Delta\eta}{\eta}$ (%)	$\frac{\Delta FF}{FF}$ (%)
Batch A-1122 Fully texturized, SiO_2 glass removed, no A.R. coating.								
High	1.22	.600	1.14	.475	13.15	.739	+8.76	+5.12
Low	1.16	.585	1.01	.460	11.30	.685	-6.53	-2.66
Wt.Ave.	1.20	.590	1.07	.465	12.09	.703		
Batch A-1123 Fully texturized, spray-on A.R. coating.								
High	1.37	.600	1.22	.470	13.93	.697	+4.30	-0.04
Low	1.29	.585	1.16	.450	12.70	.692	-4.90	-1.14
Wt.Ave.	1.32	.595	1.17	.470	13.36	.700		

L. Conveyorized Dopant Diffusion

Conveyorized dopant diffusion was investigated as an alternative dopant disposition technique. The distinguishing feature of this deposition method resides in the utilization of a conveyorized low temperature doped oxide (LTO) system. The carrier gas for the LTO system is nitrogen and the reactive gases forming the n+ source are silane, phosphine and oxygen. At the conclusion of a suitable time period, the phosphine gas is eliminated so that a layer of silicon dioxide glass may form on the wafer surface. This "cap" oxide will serve to prevent the occurrence of cross diffusion during the subsequent dopant drive-in step. Immediately following the n^+ dopant depositions, each wafer is automatically turned over by a means of a automated mechanism, thus preparing them for p^+ deposition in a second LTO system.

Several companies were identified which possessed the capability of performing low temperature doped oxide depositions. Advanced Silicon Material Co. (ASM) was selected to perform the dopant tests and to design a fixture to simulate the conveyor. Upon carrying out the experimental test runs in their LTO system, the specially designed fixturing for the 3¼ inch wafers was found to actually improve the uniformity across the wafers to an extent which exceeded the expectations of ASM.

A total of 25 cells had undergone processing in the LTO system, with a deposition time of 9 minutes at 425°C and 0.196 torr. These processed cells were received by Sensor Technology and electrical performance tests were conducted for process verification. Each test, however, yielded negative results which were attributed to surface damage incurred during processing at low pressure in a chemical reactor. Since the shunt resistance was high, surface damage, which promotes low minority carrier lifetime, is thus suspected of being responsible for the poor electrical perform-

ance of the experimental cells. While this dopant process was not thoroughly investigated, sufficient cause was found to render it unsuitable for our applications under this contract.

F. Plasma Etching of Resist

Plasma etching is a popular process in the semiconductor industry and is reportedly more economical than standard chemical methods. Its applicability extends throughout the following five areas: (1) silicon oxide or silicon nitride etching, (2) photoresist etching up to 2 μm thickness, (3) silicon surface cleaning, (4) silicon splatter removal resulting from laserscribing, and (5) higher resolution opening photolithography.

No manufacturer to-date has made any attempt to apply this method to the removal of thick film resist. The major reason for this is simply that the process is much too slow to effect the removal of a thick film resist which is approximately 5 mils thick. Consequently, no etching rate data has been made available for thick film resist. If it is assumed that the etching rate of photoresist is identical to that of the thick film resist, this would imply that an 8000Å thick film can be removed within 15 minutes as claimed for LFE Corporation's (Waltham, MA) PDS-504-AP (4) Model and thus the required process time for a 5 mil thick resist which is used in the photovoltaic industry will be approximately 40 hours. The SAMICS results for this process showed the total cost to be \$1.02 per peak watt.

In view of the above considerations, the application of plasma etching to thick film resist removal did not look very promising, and, consequently, no further effort was expended in this task.

G. Wafer Printing

The current thick film printing technology was reviewed and some of the anticipated problem areas were investigated. The current high-speed automatic thick film printing equipment was found to be completely adequate for standard catalog sold devices such as resistor networks or panel displays. A large size silicon solar cell application would, however, require a special design in order to achieve any degree of automation. An illustrative example of a typical problem area which would be encountered with this process procedure is discussed below with some suggested modifications.

The wafer printing process entails the following sequential steps: loading, printing, leveling time, drying, and unloading. The printing machine can operate at a potential rate of 7200 wafers per hour with the restriction that three-inch wafers be used. With the double head feature, it can operate at the potential rate of 7200 wafers per hour, independent of wafer size. By using the former option, it was found that the required furnaces and dryers would be prohibitively expensive and large and would also consume a significant amount of floor space.

An example that illustrates the floor space problem entailed by current thick film printing equipment is now presented. Assume that a 3.5 inch diameter wafer is printed at the rate of 7200 wafers/hr., and that the leveling time and IR drying time require up to five and fifteen minutes, respectively. Also assume that the belt width of the furnace is three feet so that ten wafers can be loaded into one row. If this is the case, then the required speed of the furnace belt will be four feet per minute and the total length of the belt will be eighty feet. Furthermore, make the assumption that the unloading device requires a minimum length of two feet. By taking into consideration the dimensional aspects

of the above components, it is clear that the printing speed will be limited by the required floor space.

This problem can be resolved if a tray-oven or overhead proofer, which is used extensively in the bakery industry, is applied. This process technique can be utilized in conjunction with a multilayer conveyor. For example, if a four layer tray conveyor is used, the overall length will be within the 25 foot range with a total oven height of five feet. This arrangement has the beneficial feature of allowing the installation of the drying chamber overhead, thus eliminating the need for excessive bottom floor space which could serve alternate functions. The only difficulty foreseen with this method is the loading and unloading process which will require a special design in order to prevent breakage of the silicon wafers.

There are several varieties of loading devices which are available in today's market such as vibratory bowl feeding, stack-type magazine and shelf-type magazine. The only suitable method found applicable to silicon wafers is the shelf-type magazine. This is the only method which incorporates the prevention of contamination or damage to the wafer surface and also protects the cell from breakage due to mishandling. The problem encountered by this method is that the magazine is unable to hold many wafers. If the printer operates at the rate of 7200 wafers/hr. then one magazine will be cured in only 1.5 minutes. Consequently, multiple magazines would be required in either a multi-position shuttle arrangement or in a multiple magazine carousel. Similar problems exist at the unloading station where the printed wafers are to be loaded into carriers which are used in the wafer plating process.

A final problem that should be considered in the wafer printing process is screen wear. A typical stainless steel mesh screen with emulsion is capable of enduring between 10,000 and 20,000 printings. Therefore, at the rate of 7200 wafers per hour, the screen will be rendered ineffectual every two hours. Recently a new type of screen has been developed with the capability of performing up to 50,000 printings. As a consequence of this development, the problem of screen abrasion is not considered to be a significant deterrent toward the attainment of 1986 production goals, if this screen performs as projected.

Most of the technology required for high speed printing is already within present day capabilities. A general review of currently available thick film printing equipment has provided the indication that state-of-the-art technology can adequately transform the throughput capability of the current machines to the elevated rate of 7200 wafers/hr.

The manufacturers possessing this capability include Presco Division of Affiliated Manufacturing, Inc., Universal Instrument Company, and Fursland Division of Hutchington Industrial Company. A cost analysis was performed with the Fursland Model 33 since it is an automated version of the equipment then in use at Sensor Technology, Inc. The Fursland Model 33 has a wafer throughput rate of 3000 wafers/hr. The SAMICS calculation indicates that the printing process cost accounts for 1.08 cents per peak watt and the drying* process cost accounts for 0.61 cents per peak watt. The total printing process cost thus becomes 1.69 cents per peak watt in terms of 1980 dollars, which is consistent with the 1986 LSA pricing goals.

*A tunnel dryer, 3 ft. wide and 26 ft. long, having a belt with a speed of 1.7 ft./min. was used to perform the cost analysis.

H. Low Pressure Vapor Metal Depositions

The original plan devised for this task was formulated exclusively to investigate the deposition of copper onto p+ silicon wafers. The low pressure vapor metal deposition of copper would serve as an ohmic back contact.

Despite the fact that ASM and the Tylan Corp., which reportedly possessed vapor metal deposition equipment were contacted, neither was found during the scheduled time phase of this program task to have successfully performed copper depositions. Consequently, any conclusive results pertaining to the viability of this process cannot be reported.

I. Wafer Plating

The electroless nickel wafer plating process was utilized in large-scale production by Sensor Technology, Inc. and was considered to be one of the lowest cost metallization processes currently practiced by the solar cell industry. It was found in this program, however, that the wafer plating process equipment, while considered to be very low-cost for the present and near term, was not sufficiently cost effective to meet the 1986 LSA cost goals.

The electroless nickel plating process equipment had two aspects which precluded this process from meeting the 1986 LSA cost goals. The first one involved an inadequate synchronization of tank sizes and process times thereby making an uninterrupted production line difficult to achieve. The second dealt with the heating of the plating solution. The electroless nickel plating bath utilized a direct immersion heater which consumed the nickel plating solution due to the deposition of nickel over the heating element. A new, synchronized, high throughput wafer plating system with an indirect heating feature was definitely needed in order to achieve the 1986 LSA cost goals.

Wafer plating process equipment was designed and constructed to circumvent the undesirable process aspects of our wafer plating system. A sketch of the electroless nickel wafer plating system is shown in Figure 17. The system has the capability of being fully automated. It has a wafer throughput capacity of 1800 wafers/hr. for three to four inch diameter wafers.

The size of each tank was determined from the criterion of allowing standard wafer carriers of all sizes to be utilized. The etchant and primer tanks are small because their process times are faster than the other process steps. Four electroless nickel plating tanks with heating elements are included. The four tanks were needed due to the fact that the nickel plating solution consumption rate is large, the process time is long, and the time required to heat the solution to 83^0 to 85^0C is relatively long (fifteen minutes). By utilizing four plating tanks, no interruption in production will occur as the result of solution preparation, since at least one tank will always be in an operational condition during the time period that another tank is being replenished.

Initial operation of the process begins when the wafers are placed into a hydrofluoric acid etchant tank for 30 seconds and then moved to the gold solution primer metal bath for 30 seconds. Next, the wafers are stored in the overflow rinse tank. After repetition of two cycles of this process, a total of six wafer carriers is collected at the overflow rinse tank. These six carriers are then placed onto a carrier basket which travels to the electroless nickel plating tanks where the wafers are processed for five minutes. The wafers are then moved into a two-stage cascade rinse tank where they remain for ten minutes (five minutes in each tank).

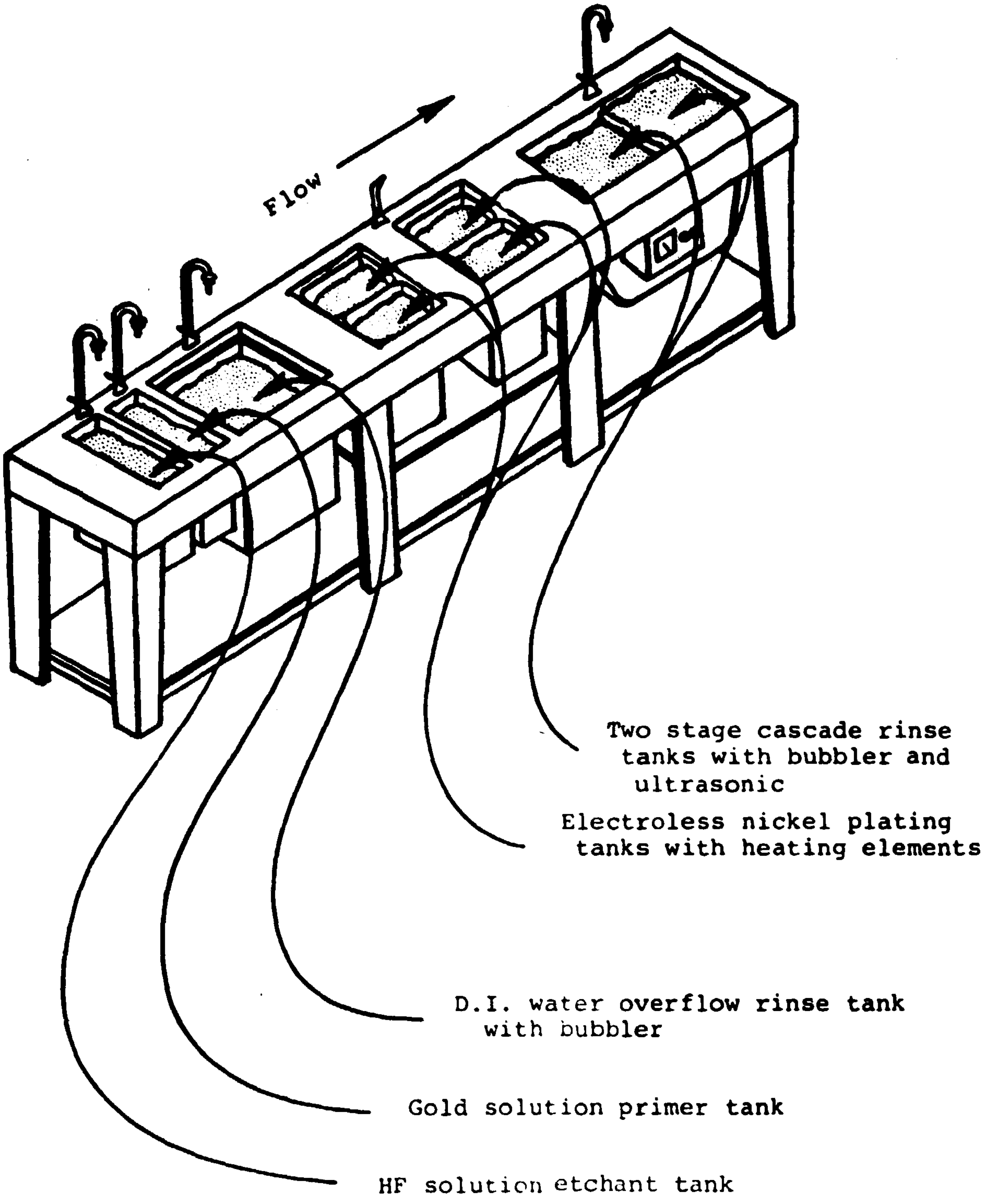


Figure 17. Sketch of Electroless Nickel Wafer Plating System

An electroless nickel plating optimization study was initiated following the installation of the new wafer plating system. The major problem which had to be overcome in the optimization study was the reduction of the material consumption rate without causing a corresponding degradation in the plating performance capability. Three hundred 90 millimeter silicon wafers were processed in order to establish the feasibility of reducing the material consumption rate. A large portion of these 300 wafers was taken directly from Sensor Technology's solar cell production line.

The important findings resulting from this process study are listed as follows:

a. The consumption rate of the gold solution was reduced by a factor of one-half.

b. The nickel solution usage time was extended by a factor of four.

c. The overall processing time was reduced by 20%.

d. The plating uniformity due to the new system had reduced the variations in cell power output from 14.7% to 4.6%.

e. The process yield was significantly increased. All 300 wafers were defect free.

The major contributing factor responsible for the improvements described above lies entirely with the use of the new, large sized bath with uniform solution and precise temperature control. A comparison among various characteristics of the new larger-sized bath and the formerly used bath will further illustrate this point.

The new gold bath has an eight liter capacity, whereas the former bath had a gold solution capacity of only three liters. The new nickel plating bath functions by means of indirect heating of the walls, while the former nickel bath used a directly submerged heating element. Consequently

the solution temperature variation in the new batch was $\pm 2^{o}C$, whereas the former nickel bath had a $\pm 5^{o}C$ temperature variation. The new nickel batch maintains precise temperature control and hence good solution uniformity. The former nickel bath had localized heat variations in the vicinity of the heater element. The localized heat variation of the former nickel bath was observed to cause breakdowns in the resist, since the resist could not withstand temperatures in excess of $85^{o}C$. In spite of the fact that the former nickel bath was maintained at $80^{o}C$, the average temperature at the wafer surface may have been higher due to poor convection of the solution.

All of these facts make it apparent that the old nickel bath solution became quickly contaminated with resist, which in turn caused the usage time of the solution to be significantly reduced. In addition, a newly installed agitation system underneath the nickel bath proved to be very effective in maintaining the solution uniformity. An increase in bath temperature to $80^{o}C$ did not lead to resist failure and the reduction in processing time from 5 to 4 minutes has not been found to sacrifice plating performance.

The new electroless nickel plating system which was designed, constructed and tested in this program has been shown to lead to a cost effective metallization process which meets the 1986 LSA goals. The SAMICS results show the cost of this wafer plating process to be 5.85 cents per peak watt in 1980 cents. The electroless nickel wafer plating system is, therefore, highly recommended for the 1986 LSA solar cell industry.

J. Solder Coating and Flux Removal

The two most widely used production line solder coating methods in the current semiconductor industry are solder dipping and wave soldering. The solder dipping method utilizes a single process cycle to solder coat one wafer at a time. The wave soldering method utilizes two process cycles; each cycle solder coats one side of a wafer at a time. The solder dipping method, while found to be more economical than the wave soldering method, was also found to have an insufficient throughput rate when compared to the 1986 LSA goals for solar cell production. A solder dipping method that replaces single wafer dipping with multiple wafer dipping was required.

A teflon carrier was fabricated and tests were performed for the purpose of establishing the solder coating characteristics of silicon solar cells processed by the multiple wafer dipping method. All studies were conducted in an existing 6" x 6" x 6" solder bath with 60/40 lead/tin solder.

The crucial parameters investigated in the experimental study were as follows:

- carrier design
- dipping direction
- wafer surface orientation
- pre-heat temperature
- cell temperature

The carrier design was dependent upon the size of the available solder pot. A teflon carrier was fabricated to hold ten 90 mm diameter silicon wafers. A wafer stop was added to prevent the wafers from floating out of the slots in the carrier during the dipping process. A ten-inch handle was also added to assist in the manual dipping operation.

The carrier dipping direction was always vertical with respect to the solder pot. It was required that the wafers be in a vertical orientation when dipped to prevent breakage. It was also found to be necessary to shake the wafer carrier after dipping and to place the solar cells in a horizontal position to prevent non-uniformity of the solder coatings.

In the automated P.C. board industry, an air knife-edge is used to replace the manual technique discussed above to produce uniformly solder coated solar cells. This technique was used in the SAMICS analysis discussed in a later section of this report.

The operating temperature of the solder bath was found to be very important for multiple wafer dipping. At a temperature of 450^{o}F (232^{o}C), the solder coagulated on both the front and back surfaces of the solar cells which indicated that this temperature was too cold. When the temperature was raised to 500^{o}F, (260^{o}C) good solder coating uniformity was observed only after adopting the dipping procedure which involved the removal of excess solder by shaking the vertically positioned solar cells and then cooling the cells in a horizontal position. When the dipping operation was carried out at this temperature without utilizing this procedure, the solder coagulated in isolated segments on the back surface of the solar cell, which resulted in non-uniform solder coatings. For temperatures in excess of 600^{o}F, (316^{o}C) the cells incurred excessive breakage due to thermal stresses. The thermal stresses could be relieved by preheating the wafers, a common technique used in the P.C. board industry, but this was not investigated in detail in this program. Consequently, it was concluded that the optimum temperature range providing solar coating uniformity for multiple wafer dipping was 500 to 550^{o}F with the restriction that the dipping procedure described above is utilized.

Three flux removal process methods were studied in this program and are listed as follows:

- D.I. water rinse tank
- D.I. water cascade rinse system with nitrogen bubbler
- D.I. water cascade rinse system with ultrasonic agitator

The first method was found to be unsuitable because flux residue was observed on the surface of the D.I. water which coated the solar cells when they were removed from the rinse water. The second method was also found to be ineffective in cleaning the flux off the solar cells. The third method which utilizes a D.I. water cascade rinse system with ultrasonic agitator was found to be an excellent method for flux removal.

The process sequence consisted of a three-stage D.I. water cascade rinse system with ultrasonic agitator. The process time was two minutes for each stage. The water temperature was 90^{0}C. The high D.I. water temperature will allow one to dry the wafers in a clean room environment and thus eliminate any heater or oven equipment which is typically used in present systems. The D.I. water cascade rinse with ultrasonic agitation in the first tank is a highly recommended flux removal process.

K. Silicon Nitride AR Coating

Development of high efficiency, low-cost solar cells requires the utilization of a low-cost process procedure for applying antireflective coatings. The method utilized by Sensor Technology at the time of this investigation was silicon monoxide evaporation. This process step was expensive due primarily to its low throughput capacity and high electrical power consumption rate. In order to meet

future pricing goals, it would therefore be desirable to formulate a new, more efficient and low-cost AR coating process method.

K1. Current Technology

One of the most technologically advanced AR coating methods now in existence is silicon nitride coating by means of plasma deposition. Considerable effort, therefore, was channeled toward the investigation of this technique.

Initial work was directed toward identifying the most advantageous method available for the plasma deposition of silicon nitride onto silicon solar cells. Four companies were considered. They include Texas Instrument (T.I.), Advanced Material Technology (AMT), Tegal Corporation, and LFE Corporation. Among the four representative systems, the T.I. and AMT system characteristics were almost identical. Due to this similarity the T.I. system will not be considered in this discussion. Although a large number of parameters was used in the evaluation of each system, only the most crucial parameters are discussed below.

The key process information pertaining to the three companies is given in Table 12. It is clear that the LFE system maintains a minimal power and gas consumption rate in relation to the other systems. The concentration of silane gas used by the Company A and B systems approaches the six to eight percent range as opposed to the LFE system which consumes only one and one-half percent.

The wafer throughput of each system is a parameter of far-reaching significance. The throughput comparison of the three companies is given in Table 13. This table displays two throughputs; one is indicative of the recharacterizing process, and the other is not. Both the

Table 12. Comparative Operation and Information of Silicon Nitride Antireflective Coating Manufacturers.

	LFE	A	B
Power Consumption (Deposition Mode)	4.5 KVA	25.0 KVA	10.5 KVA
Water	Not required	6 GPM	1 GPM
Exhaust	1"	2"	1"
Compressed Air	0.05 ft^3/hr.	0.2 ft^3/hr.	0.2 ft^3/hr.
Deposition Gases	1½% Silane / Ar, N_2	Silane, N_2 (1). Ammonia	Silane, N_2 (1), Ammonia
Cleaning	$(CF_4 + O_2)$ (2) (3)	CF_4 (3)	$CF_4 + O_2 + N_2$ (3)
Vacuum Pump (main)	1100 L/M	990/6600 L/M	720 L/M

(1) Requires special storage area and safety precautions.
(2) LFE Patented Process U.S. Patent #3,795,557.
(3) LFE - recommended (minimum) cleaning every 4 hours.
A & B after every run.

Note: Process must be recharacterized after cleaning. This frequent cleaning is suggested due to significant particulate contamination problems; however, it is only marginally effective.

Table 13. Wafer Throughput Table for Silicon Nitride Antireflective Coating Manufacturers.

	Max Wafers Per Batch		Batch Cycle (time in min).		Throughput W/O Recharacterizing		Throughput W/Recharacterizing	
	Diameter 3" - 100mm		Without Recharacterizing	With Recharacterizing after Plasma Clean	Wafers/hr. 3"dia.- 100mm dia.		Wafers/hr. 3" dia.-100mm dia.	
LFE	N.A.	N.A.	N.A.	N.A.	40	40	40	40
A	28	28	49	68	34 *	22 *	25 **	16 **
B	35	20	43	62	49 *	28 *	34 **	19 **
							Typical throughputs based on customer feedback	

N.A. - Not Applicable

* - Throughput computed without recharacterizing

** - Throughput computed with recharacterizing

A and B company systems require recharacterizing processes due to the severe particulate "sandstorm" caused by the batch system design. Often this recharacterizing process is required for MOS applications. Even without taking into account the recharacterizing process, the LFE system demonstrates high wafer throughput.

The important direct process costs for each process method have been estimated and a comparison is shown in Table 14. These estimates do not take into consideration such factors as overhead, floor space, and equipment costs. However, the above estimates can be used to elicit a relative comparison among the different systems. The results indicate that the process costs of the LFE system are only one-eighth that of Company A and only one-third that of Company B. Even though these estimations yield only approximate results, it is apparent that the LFE system will provide greater cost effectiveness than the other systems.

The results of the silicon nitride plasma deposition systems study discussed above show that the LFE system will provide the greatest efficiency both in terms of technical capability and operating costs.

A comparison will now be made between LFE's System 8000 and Sensor Technology's SiO Kenney evaporation system. The process costs for both systems have been computed in accordance with the SAMICS method which makes the underlying assumption that the wafer diameter is 90 mm and the peak watt output is 0.653 watts. The monetary values are in 1980 dollars. The results are specified in Table 15. These results indicate that the evaporation method is approximately twice as expensive as the LFE plasma deposition method. It also shows that the evaporation process will require considerable developmental improvements in order to achieve automation and to reduce power consumption while the LFE system will require a reduction in the equipment cost or an increased wafer throughput.

Table 14. Direct Wafer Process Cost for Silicon Nitride Antireflective Coating and Manufacturers.

	A	B	LFE
GASES	$.238	$ .063	$ .036
ELECTRICAL POWER	$.06	$ .02	$ .006
LABOR	$.06	$ .05	$ .003
COST PER WAFER	$.358	$ .133	$ .045
EQUIPMENT COST *	$75,000	$47,000	$75,000

*Domestic price

Size of wafer is 3" or 4 "

Note: This analysis was made in 1978. Although relative price ratios are expected to remain approximately the same, absolute values have changed.

Table 15. AR Coating Cost in 1980 Dollars Per Peak Watt for 3.5" Diameter Silicon Solar Cells, 0.653 watts/cell.

	Kinney's SiO Evaporator	LFE System 8000 Silicon Nitride Plasma Depositor
Materials	0.1365	0.1320
Labor	0.3245	0.0535
Utilities	0.2433	0.0232
Equipment	0.0321	0.2103
Floor Space	0.0356	0.0248
By-Produce Expense	0.0154	0.0248
Total	0.7874	0.4438

In view of the above considerations, the LFE System 8000 was selected as a potential mechanism for depositing silicon nitride antireflective coatings onto silicon solar cells. Consequently, a detailed description of the LFE System 8000 will be presented along with the proposed equipment modifications designed to elevate the existing silicon wafer throughput.

K2. Description of the LFE System 8000

The LFE System 8000 is presently being utilized by semiconductor manufacturers to deposit 5000Å to 8000Å of silicon nitride onto silicon wafers, in part to provide a hermetic encapsulant. A simplified diagram which delineates the overall system design can be found in Figure 18.

The LFE System 8000 is composed of a vacuum processing chamber which contains five separate process zones with the wafer receiving 20% of its total film in each zone in a sequential manner. The wafer must pass through a vacuum lock at the entrance to the chamber and exit the chamber through an identical vacuum lock after it has been processed at all five process locations. Upon completion of this procedure, a fully coated wafer will emerge every 120 seconds. This figure incorporates the 60 seconds expended for the plasma deposition of 800Å of silicon nitride onto the silicon wafers, as well as the 60 seconds required for the wafer movement through a vacuum lock on the main track. The wafer throughput of this system is, therefore, only 30 wafers per hour. This throughput rate will need to undergo considerable improvement in order to conform to the stipulations set forth in the 1986 LSA pricing goals.

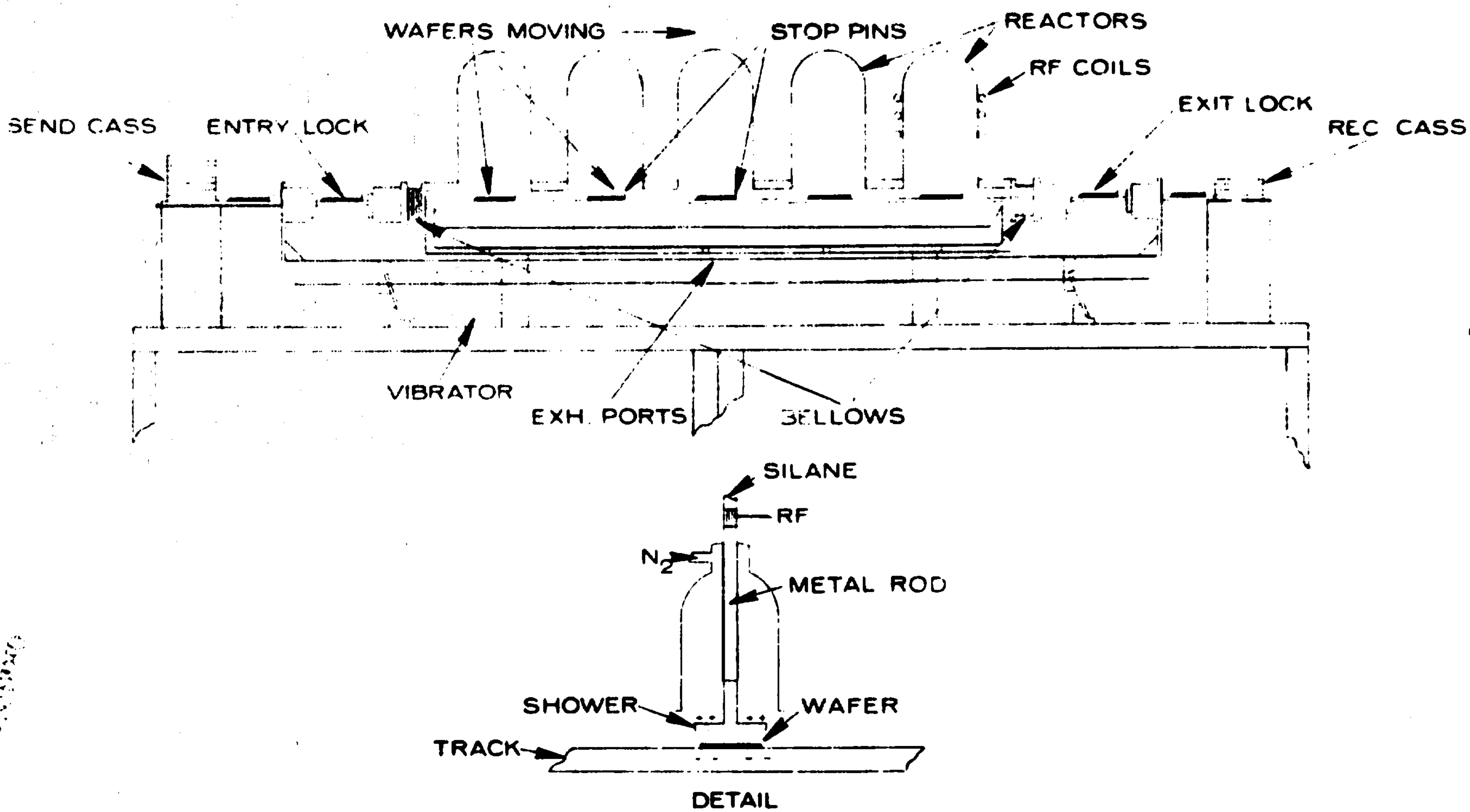


Figure 18. LFE 8000 System for Silicon Nitride Antireflective Coating.

K3. Possible Modifications to the LFE System 8000 for an Enhanced Wafer Throughput

Feasible modifications of the LFE System 8000 silicon nitride plasma deposition equipment could be made which would significantly enhance the wafer throughput beyond the present rate of 30 wafers/hr. A new wafer throughput rate of 300 wafers/hr. could be achieved. In order to arrive at this goal, the total processing time must be reduced from two minutes to one minute. This reduced processing time includes 40 seconds to deposit 800Å of silicon nitride (at a rate of 1200Å per/min.) and 20 seconds to load and unload the wafers. Five wafers could be deposited simultaneously, i.e., each wafer will make only one stop within the process chamber instead of the present requirement of five stops.

The system operation would then be divided into two time periods. In the first period, movement of five unprocessed wafers into an entry lock from the sender will take place at the same time that five processed wafers are moved out to the exit lock into the receiver. While this wafer movement occurs external to the chamber, wafer depositions will take place within the chamber.

In the second time period, a sequential movement of five processed wafers from the process chamber into the exit locks, and then a movement of five unprocessed wafers from the entry lock into the process chamber will take place. This process sequence would occur within the allowed processing time to achieve the enhanced throughput goal of 300 wafers/hr.

The key design modifications which will facilitate an enhanced wafer throughput are as follows:

(a) The wafer velocity on the process track should be increased and the positioning control improved. It is imperative that the wafer velocity on the process track be increased from 2" per second to 3" per second. This can be achieved by redesigning the vibratory subsystem so that an upper velocity limit is established. Since each wafer must be accurately positioned in the process zone in order to obtain the proper degree of film uniformity, it is necessary to provide a "stop pin" on the process track. The stop-pins retreat into the track during wafer movement and then resurface when the wafer approaches the proper position. The wafer movement is controlled by a microprocessor which receives wafer positioning data from the capacitive sensors which are imbedded in the process track. The microprocessor controls the turn-on of the vibratory mechanism and the mode of the stop-pins in accordance with the particular timing sequence under consideration and wafer positioning information.

(b) The wafer transition time through the vacuum locks should be decreased. The transition time of a single wafer from the sender to the vacuum lock, and then from the vacuum lock to the process chamber, is 30 seconds for the present system. In order to move five wafers through this sequential transition operation within a 40 second time period, a new design is required. This new design has a cassette mechanism located within the entry lock (and also the exit lock) allowing for a buffer of five wafers in the "ready" zones, namely, the entry and exit locks. As each wafer moves into the lock cassette, the cassette will index up (or down) one notch in preparation for the next wafer until all five wafers are received (or dispatched in the case of the exit lock).

The technical staff at LFE Corporative has accumulated extensive experience with the System 8000 and could foresee no immediate problems associated with the adoption of the state-of-the-art equipment modifications described above.

K4. Performance Verification Test of the LFE System 8000 and Analysis of Silicon Nitride AR Coatings on Solar Cells

A performance verification test of the LFE System 8000 silicon nitride plasma deposition equipment was made. This test was implemented by comparing the I-V curves of texturized silicon solar cells which had undergone the silicon nitride AR coating process with the I-V curves of identically processed (same batch) solar cells without an AR coating. Upon analysis of the average I-V curves, which are shown in Figure 19, it was found that the texturized solar cells coated with silicon nitride displayed a significantly improved electrical performance over the uncoated texturized solar cells.

To illustrate this point, I_{sc} for the AR coated cells was found to be 1.42 amps with a corresponding efficiency of 11.3%, whereas, for the uncoated cells, I_{sc} was 1.25 amps with a corresponding efficiency of 9.9%. Therefore, a relative improvement in electrical performance of 14.1% was achieved through the application of silicon nitride AR coatings to texturized silicon solar cells verifying the performance of the LFE System 8000 silicon nitride plasma deposition equipment.

A solar cell electrical performance analysis was also conducted to determine the feasibility of inserting an antireflective coating step within the overall solar cell process sequence. A silicon nitride AR coating was applied to texturized silicon wafers after the $POCl_3$ diffusion step and prior to the metallization process sequence.

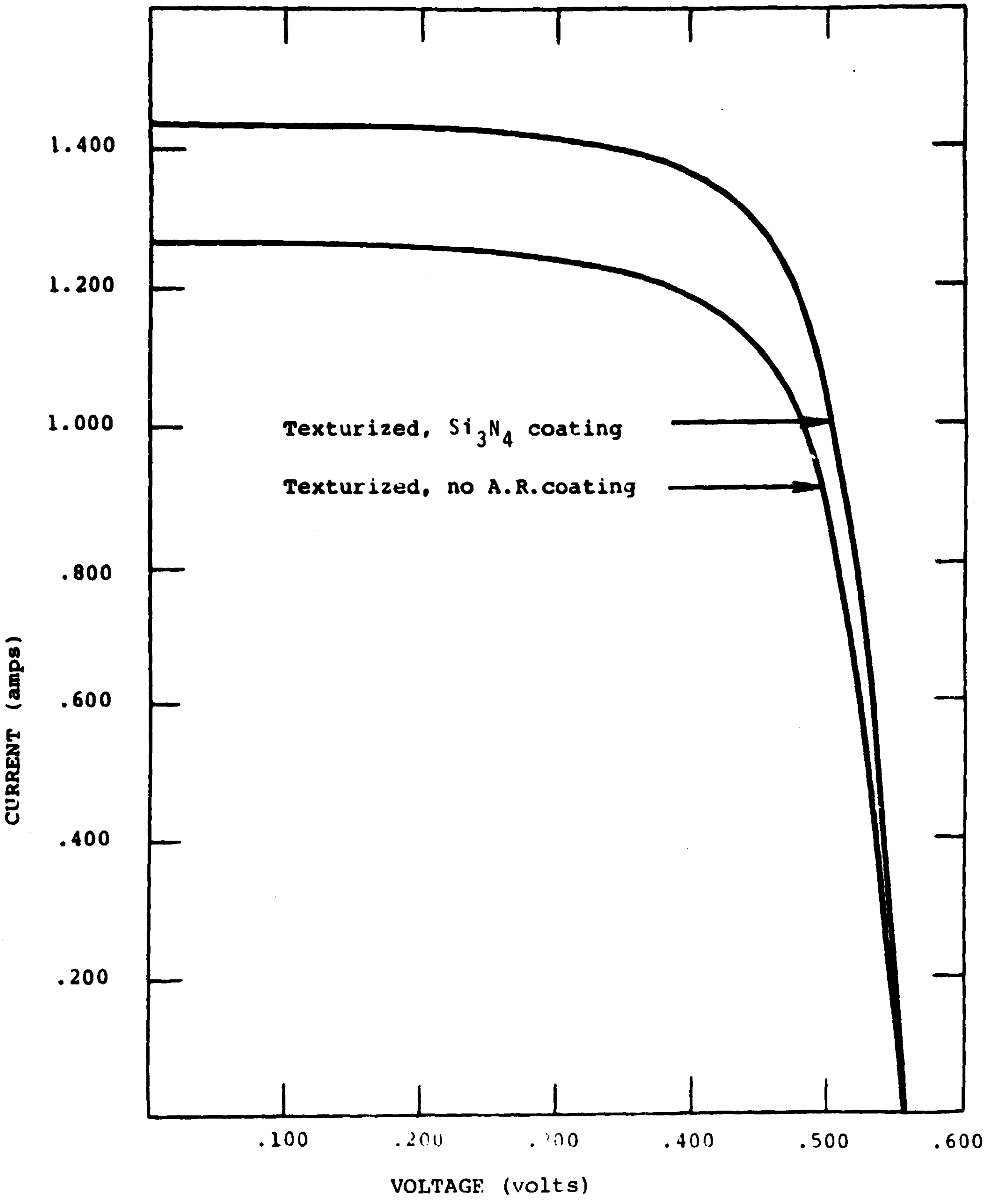


Figure 19. Electrical Performance Curves of Texturized Solar Cells with and without a Silicon Nitride (Si_3N_4) Antireflective Coating. The Solar Cells are Hexagonal with 50.8 cm^2 Active Area. They are Tested at 28°C, 100 mW/cm^2 under Tungsten Light.

Immediately after recording the solar cell electrical performance, the antireflective coating was removed with HF and then the electrical performance was recorded again. The two sets of data are shown in Figure 20 and are also tabulated in Table 16 for comparison.

The difference in photovoltaic energy conversion efficiencies was substantial; a 31% difference was observed between AR coating and the same solar cells with the AR coating removed. The number of solar cells tested was too small to formulate any definite conclusions; however, there is an indication that improved solar cell efficiencies are possible by means of an in-process AR coating procedure. It is recommended that a detailed and thorough investigation of the application of in-process AR coatings for solar cells be performed.

K5. Cost Analysis for the Modified LFE System 8000

A SAMICS cost analysis was performed to compare the present LFE System 8000 process sequence with the modified process sequence discussed above. The process cost for the 300 wafer/hr. modified silicon nitride plasma deposition system was computed on the basis of the following assumptions:

(a) The electric power consumption rate will increase by 35% due to the power requirement of the vibratory structure.

(b) The equipment cost is expected to increase by approximately 35% of the current price due to the addition of a transition buffer system and larger microprocessor unit.

(c) The material consumption rate is proportional to the deposition rate which will remain identical to that of the current LFE 8000 system.

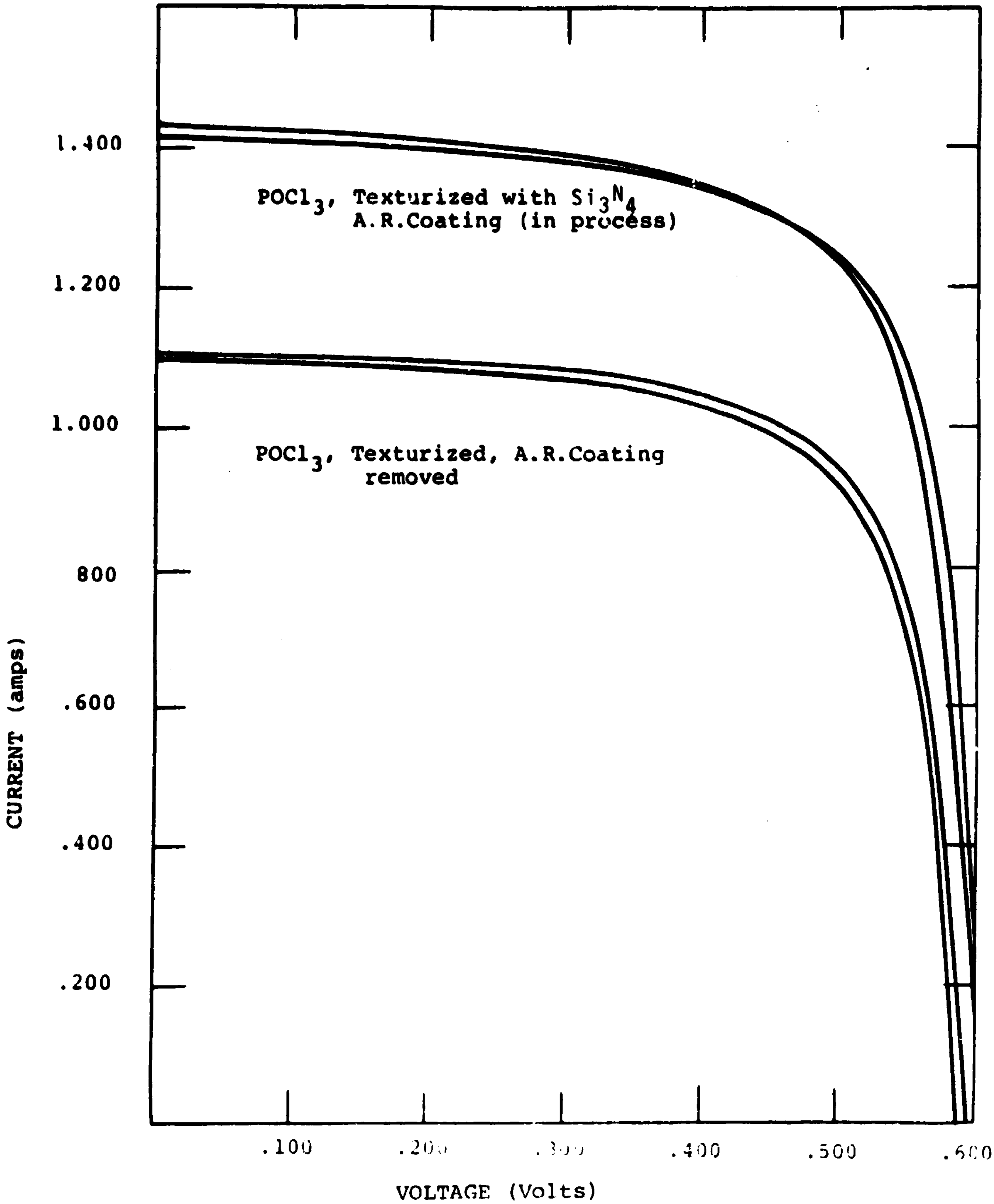


Figure 20. Electrical Performance Comparison between Texturized Hexagonal Solar Cells with and without Silicon Nitride (Si_3N_4) AR Coatings. Si_3N_4 was Applied in process. Cells have an Active Area of 45 cm^2 and were Tested at 28°C Under 100 mW/cm^2 Tungsten Light.

Table 16. Electrical Performance Comparison between Texturized Hexagonal Solar Cells with and without Silicon Nitride (Si_3N_4) AR Coatings. Si_3N_4 was Applied in process. Cells have an Active Area of 45 cm^2 and were Tested at 28°C under 100 mW/cm^2 Tungsten Light.

Cell No.	Isc (a) Hex	Voc (v) Hex	Ipp (a) Hex	Vpp (v) Hex	Ppp (w) Hex	FF Hex	η(%) Hex
$POCl_3$, Texturized, Si_3N_4 (in process) Solar Cells							
1	1.43	.61	1.27	.475	.603	.691	13.41
2	1.41	.61	1.27	.475	.603	.701	13.41
Avg.	1.42	.61	1.27	.475	.603	.696	13.41
$POCl_3$, Texturized, A.R.Coating Removed, Solar Cells							
1	1.11	.595	1.00	.465	.465	.704	10.33
2	1.10	.590	.98	.465	.465	.703	10.13
Avg.	1.10	.592	.99	.465	.465	.703	10.23

The results of a detailed SAMICS calculation of the silicon nitride AR coating process are shown in Table 17. The SAMICS result of 5.59 cents per peak watt in 1980 cents for the modified LFE System demonstrates a near order of magnitude decrease relative to the unmodified system. Although 5.59 cents per peak watt in 1980 cents is high, this process cost is still consistent with the 1986 LSA pricing goals for the overall cost of the wafer.

L. Laser Trimming and Holing Operation

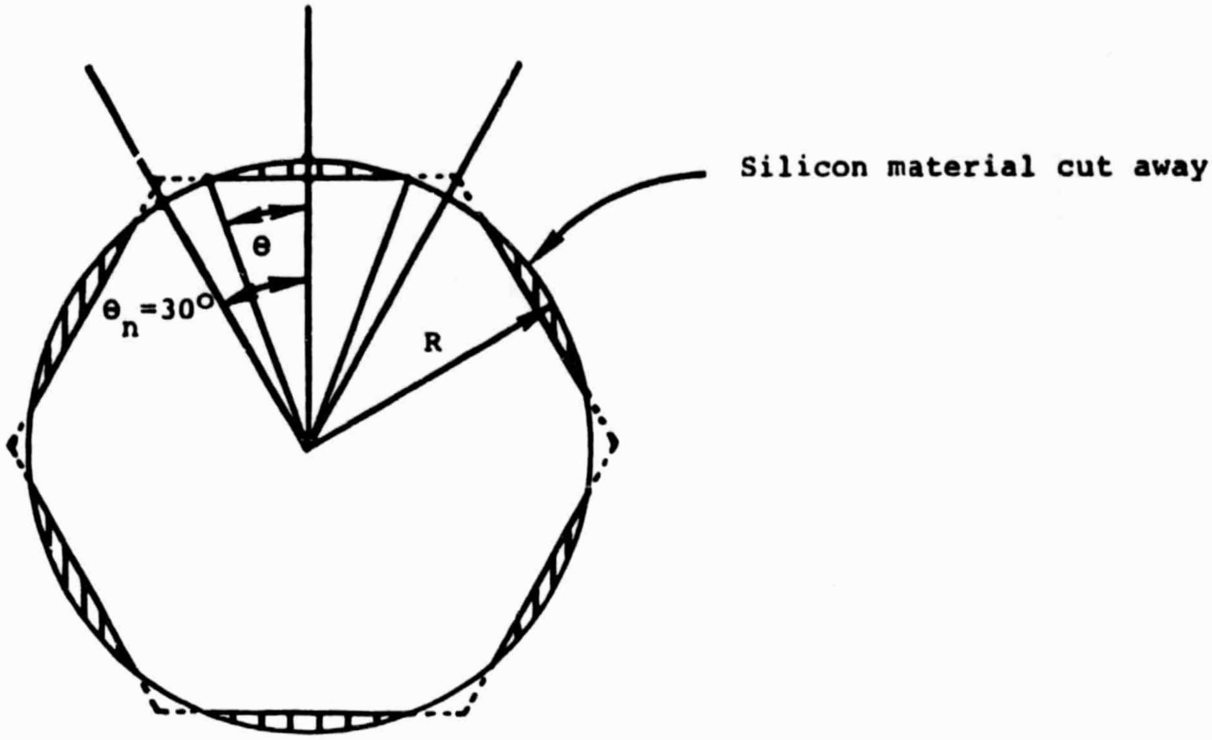
The concept of hexagonal solar cell trimming and holing by laser was formulated exclusively by Sensor Technology, Inc. in response to the overwhelming need for high efficiency, low-cost solar cells and solar cell modules.

The advantages derived from using a laserscribe to cut hexagonally shaped solar cells from round solar cells are two-fold. The first advantage lies in the significantly increased solar cell module packing efficiency available from hexagonal solar cells in relation to round solar cells. This improvement in packing efficiency will serve to reduce the overall module packing material and surface area requirements for any designated module power output. Ostensibly, however, the reduction in space utilization described above will occur only at the expense of silicon wafer material utilization, since the hexagonal wafers are scribed directly from larger area round wafers. To circumvent the disadvantages associated with the tradeoff between silicon material utilization and module packing efficiency, it was concluded from a former study (ERDA/JPL-954605-78/5 Final Report) that a compromise in the form of a modified hexagon, as shown in Figure 21, will lead to an optimal utilization of silicon material.

Table 17. The 1986 Antireflective Coating Process Cost in 1980 Dollars Per Peak Watt.

	LFE System 8000	Modified LFE System
Equipment	0.2103	0.0260
Floor Space	0.0248	0.0017
Labor	0.0535	0.0132
Materials	0.1320	0.0112
Utilities	0.0232	0.0038
Total	0.4438	0.0559

C-2



R = radius of silicon wafer

θ = half secant angle of a modified hexagon

θ_n = 30°, half angle of a full hexagon

Figure 21. Definition of a Modified Hexagon.

The second major advantage derived from laserscribing hexagonal solar cells was first discovered in JPL Contract 954605. It was found in that program for the development of low-cost, high energy-per-unit-area solar cell modules that the laserscribe can reduce junction current leakage losses by trimming the edges of solar cells; it can cut through the p-n junction (without conductive coatings) without damaging the junction; and that the junction current leakage caused by edge effects from the laserscribe is uniform, consistent and very small.

A major new concept developed in this program utilizes the laserscribe to cut a hole in a solar cell. This holing or trepanning operation involves the removal of a circular plug at the wafer center. This technique is imbued with a dual purpose. The central hole is an integral component of a novel solar cell design (see Task Q) which utilizes central hole current collection, as opposed to the conventional method of edge current collection. In addition to enhancing the power conversion efficiency of these solar cells, the central hole will facilitate module fabrication by reducing the number of required solar cell interconnections.

In view of the above considerations, it is evident that the laser trimming and holing operation will lower the overall module processing costs and contribute to an improvement in solar cell power conversion efficiency. The Quantronix Corporation Model 603 laserscribe system shown in Figure 22 had the technological capability of laser trimming and holing, however, a special computer program was required which allowed us to achieve this laser trimming and holing objective. Quantronix Corporation was therefore subcontracted to develop a hexagon/central hole computer program logic board and to program accordingly the Model 603 laserscribe.

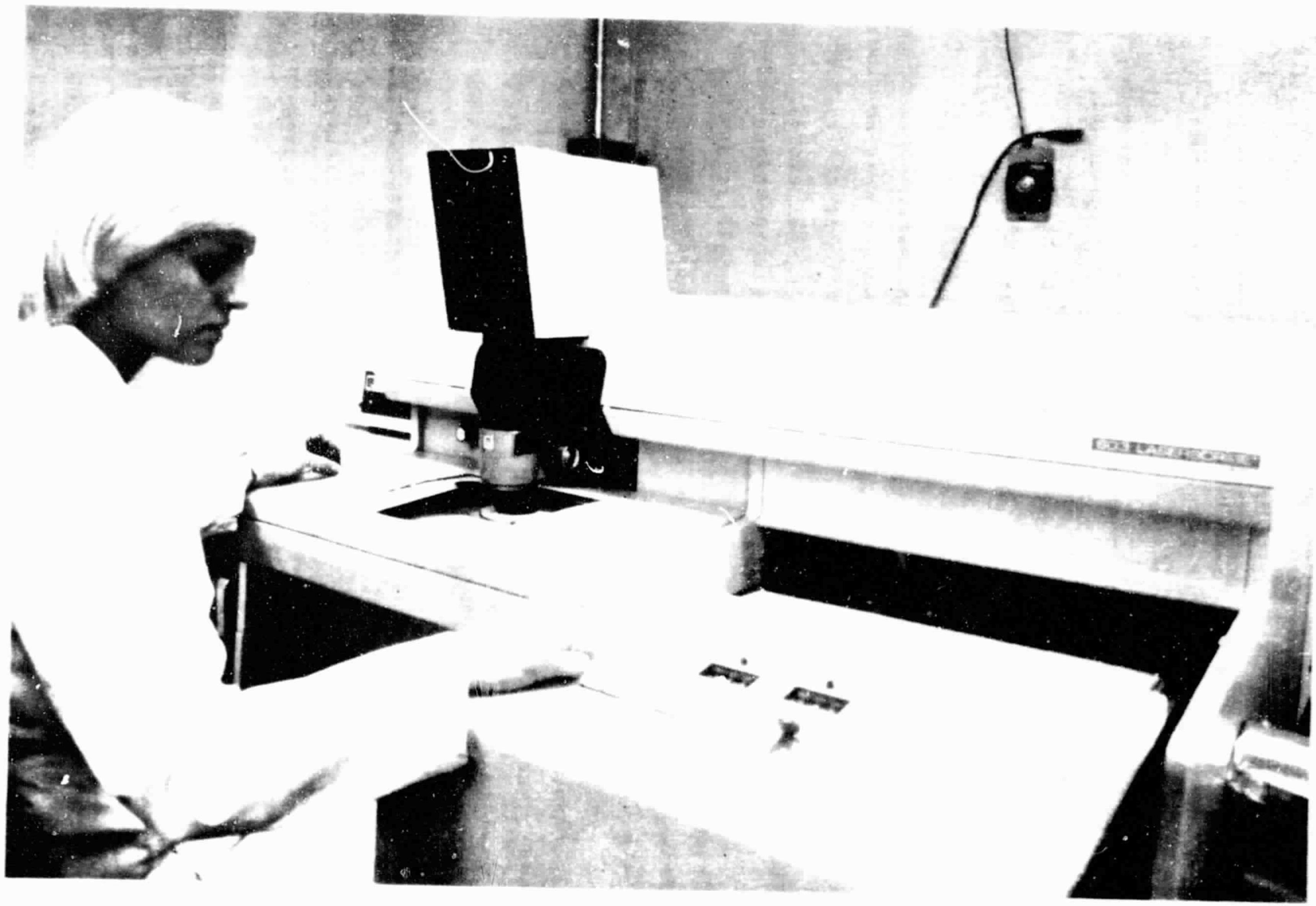


Figure 22: Laserscribe Used to Cut Hexagonal Solar Cells and Center Hole from Circular Solar Cells.

The hexagon trimming and holing operation program consists of three main features. A special servo program permits motion of the table (or wafer platform) in straight line segments at arbitrary angles thereby generating standard, hexagonal, or circular patterns with respect to the X-Y axes. The laser trimming and/or holing operation can occur through one of the following six optional subroutines.

OPTION 1. Standard X-Y laserscribe program as specified by Quantronix Corporation.

OPTION 2. Scribe hexagon with the following inputs:

a) Wafer diameter specified by two digits, i.e. X.X inches.

b) Radius of circumscribed circle from one inch to two inches specified by three digits, i.e. 1.XX inches.

c) Corner cut specified by three digits i.e. .XXX where 0, if given, means no cut.

OPTION 3. Scribe hexagon in half from point-to-point.

OPTION 4. Scribe hexagon in half perpendicular to Option 3 or from the center of one side of the hexagon to the center of the opposite side.

OPTION 5. Central hole cut with the following characteristics:

a) Holing process begins with wafer center placed within $\pm$ 5 mils of hexagon center.

b) Diameter restricted to lie within range of 100-500 mils.

OPTION 6. Generation of central hole in conjunction with scribed hexagon as specified in Options 2 and 5.

A special monitor program produces the appropriate position coordinates and velocity data. Special hardware enables the above patterns or options to be produced with accuracy at high speeds.

Experiments were performed to demonstrate the capability of the laserscribe with logic board to scribe and trepan (or hole) hexagonal solar cells. In their final report to Sensor Technology, Quantronix Corporation presented documentation of their studies, and concluded that their laserscribe and logic board yield favorable results. This was confirmed by Sensor Technology on its laserscribe equipment. The results are discussed below.

The silicon solar cells were scribed by laser and the excess removed by breaking away in order to investigate the feasibility of mechanically removing all excess wafer material remaining after formation of the hexagonal shape. All wafer samples were inspected for edge quality and found to be acceptable. Of the sample lot of ten wafers which was processed for the mechanical wafer cracking experiment, one wafer was broken across the wafer face, which constitutes a failure. However, the ease with which cracking occurred demonstrated the feasibility of the method.

The viability of laser trepanning silicon solar cells was tested. Quantronix Corporation was completely successful in their experiments. After making some necessary optical adjustments involving the laser focal point depth for cutting a central hole, Sensor Technology achieved very good results. The laser holing operation was tested with twenty-five wafer samples under the following process parameters.

Number of Samples:	25
Laser Power:	17.5 watts
Q Switch Frequency:	10 KHz
Laser Mode of Operation:	"B"
Table Speed:	2.0 in./sec.(in linear cutting mode)
Number of Passes:	12
Cutting Time:	10 seconds
Hole Diameter:	0.2 inches

Twenty-four out of twenty-five wafers were successfully scribed which constitutes a 96% yield factor.

The operational simplicity, high yield factor, and demonstrated technological capability of the laserscribe equipment in trimming and holing solar cells, are indicative of the overwhelming success of the laser trimming and holing operation. This technique is highly recommended; however, in order to comply with the 1986 LSA production goals, it is essential that the laser trimming and holing operation be fully automated. An indepth discussion of laser trimming and holing automation is presented in Task M.

M. Laser Trimming and Holing Automation

The utilization of a low-cost, fully automated laserscribe system which maintains a high volume throughput and large output yield, will be of central importance in achieving the 1986 LSA goals. Consequently, a study was devised which set out to identify a system possessing the above mentioned features, with the capability of accepting a batch of wafers in the form of a multiple track conveyor. The system will receive wafers from the conveyor, orient and position the wafers, scribe and trepan the wafers, break along the hexagonal scribes and remove the trepanned plugs, and finally, reload the finished wafers onto the conveyor.

Two potentially automated systems capable of laserscribing silicon wafers to produce hexagonally shaped wafers with central holes were identified and reviewed in order to establish the output capability, maintainability, reliability, and economic characteristics of each system.

The first system considered was the parallel flow laserscribe system. It contains four dual beam lasers aligned as shown in Figure 23. Wafers are off-loaded from cassettes, aligned and loaded onto platens accepting eight wafers each. The loaded platen is moved to the X-Y table where it is keyed and locked in position under the laser beam. The table is programmed to scribe first the hexagon and then the central hole.

The platen containing the scribed and trepanned wafers is next moved to the cracker unit where the edges and the center hole materials are removed from all eight wafers at the same time. The scribed and trepanned wafers are carried to the packer to be off-loaded from the platen and loaded into cassettes. The scrap is collected and returned by conveyor to the recycling station. Note that the various operations - loading/aligning, scribing/holing, cracking, and packing operations - are simultaneous steps timed so that each operation is accomplished in the same time interval. The time interval between wafer sets depends on scribing time and the time required between moves.

A detailed cost breakdown for the parallel flow laserscribing system with throughput rate of 4800 wafers per hour is presented in Table 18. The total cost per peak watt for the parallel flow laserscribing system in the 1986 and 1980 cents, respectively, are 1.7886 cents and 1.3047 cents.

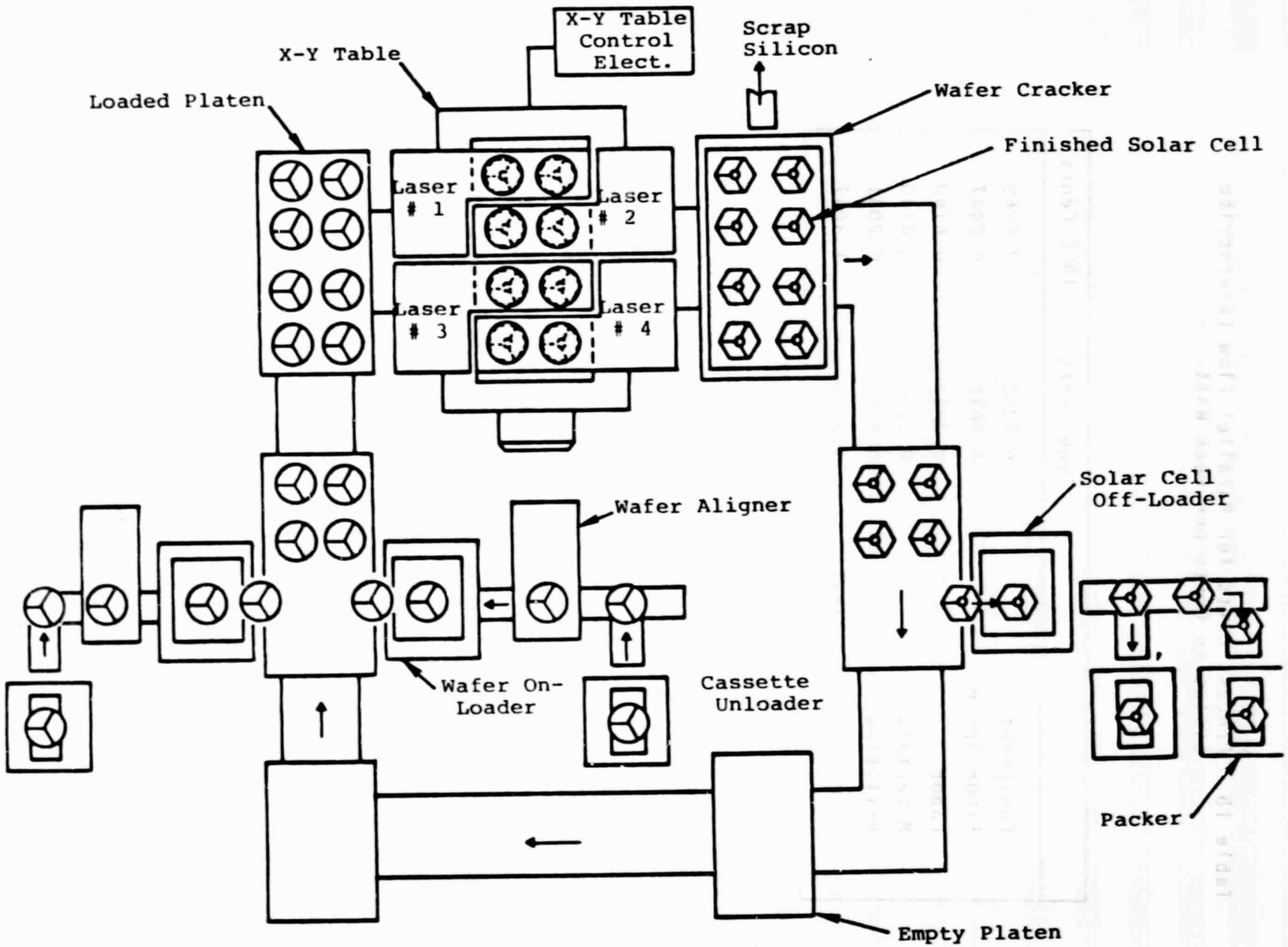


Figure 23. Parallel Flow Laserscribe System for 4800 Wafers Per Hour

Table 18. Process Costs for Parallel Flow Laserscribe System in Cents per Peak Watt.

	1986 Cents	1980 Cents
Equipment	0.5850	0.4269
Floor Space	0.0612	0.0447
Labor	0.8449	0.6160
Materials	0.0192	0.0140
Utilities	0.2783	0.2031
Total	1.7886	1.3047

The second system considered was the serial flow laserscribe system. This unit is comprised of 2 loaders, 2 aligners, 3 dual beam lasers, 4 trepanning (holing) lasers, 4 wafer crackers and a moving surface onto which are mounted, at evenly spaced intervals, wafer holding chucks as shown in Figure 24. One wafer at a time is removed from its storage container and transferred onto a holding chuck which carries the wafer through the scribing process. The wafer is moved along by conveyor to the wafer aligner where the wafer grid lines are oriented in preparation for scribing.

The wafer is then passed under a dual beam laser whose beams are aligned and focused so that two parallel sides of a hexagon are simultaneously scribed. The wafer is next moved at constant speed to the chuck rotator which is indexed to turn the wafer 60^{0}, and it will then be transferred to laser number 2 where the second pair of parallel sides is scribed. The partly scribed wafer is again rotated 60^{0} and the last pair of parallel sides is scribed by laser number 3. The hexagon scribed wafer will be offloaded from the conveyor and then distributed to the trepanning (holing) scriber/cracker units. Since it takes four times as long to produce holes as to scribe the hexagon, four trepanner/cracker units are needed for each hexagon scriber unit.

The finished wafers are finally off-loaded from the trepanner/cracker and loaded onto the carousel conveyor which carries them to the packer where the scribed wafers are returned to storage containers. The empty chucks are transferred to the return conveyor and to the loader to receive the next wafer. The scrap silicon, meanwhile, is collected and returned to the recycling station.

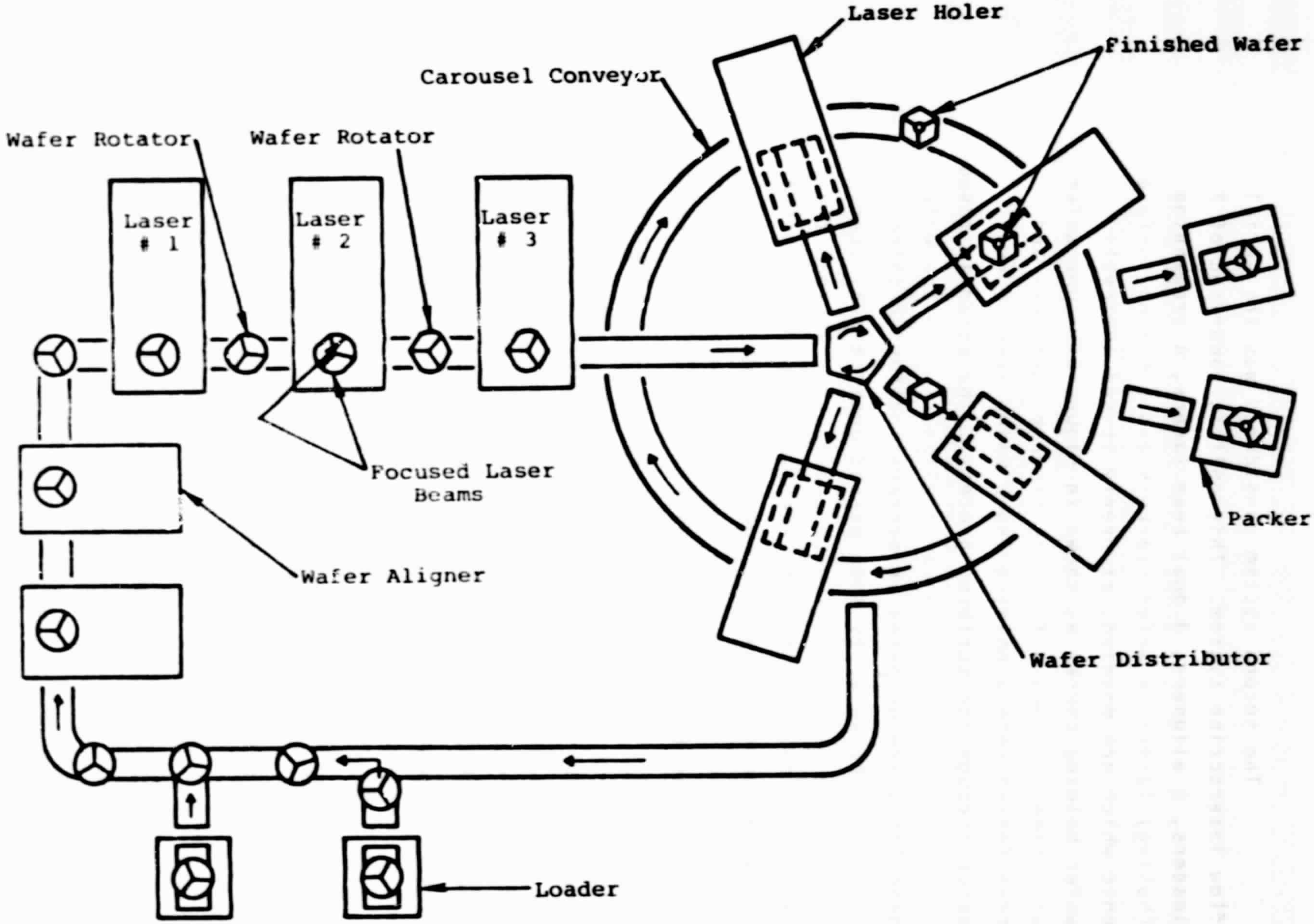


Figure 24. Serial Flow Laserscribe System for 7200 Wafers Per Hour.

A detailed cost breakdown for the serial flow laserscribing system with a throughput rate of 7200 wafers per hour, is presented in Table 19. The total costs per hour is presented in Table 19. The total system in 1986 and 1980 cents are 1.4903 cents and 1.0878 cents, respectively.

Upon comparison of the process costs of the two laserscribing systems in Table 18 and Table 19, it is evident that the serial flow laserscribing system is more cost effective than the parallel flow system. The critical cost factors for the serial flow system lie with the equipment and labor costs.

On the basis of the analysis presented in this section, it can be concluded that the serial flow laserscribing system displays the characteristics which are essential for achieving the goals of the 1986 Low-Cost Solar Array Program.

N. Laser Scanning Inspection

An investigation of three types of wafer scanning procedures was conducted for the purpose of selecting a suitable method for the detection of mechanical defects in solar cells.

The first method under consideration was the x-ray scanning method which has a demonstrated capability of detecting mechanical failures. There is, however, a serious drawback with this method of scanning silicon wafers for the detection of mechanical defects. The suitable technique for data acquisition of this type of x-ray scanning is not available at the current technology. This data acquisition problem could be eventually overcome, but only as the result of extensive study which is well beyond the scope of this task.

Table 19. Process Costs for Serial Flow Laserscribe System in Cents per Peak Watt.

	1986 Cents	1980 Cents
Equipment	0.5179	0.3780
Floor Space	0.0575	0.0420
Labor	0.6713	0.4900
Materials	0.0077	0.0056
Utilities	0.2359	0.1722
Total	1.4903	1.0878

The second method investigated was IR-Micro-Inspection developed by Electrophysics in New Jersey. It was found that with this method, the detection of soldering faults would be extremely difficult, and consequently, this procedure was not suitable for our requirements.

The third method investigated was laser scanning. This method for detecting mechanical defects in silicon material is presently being studied at the Jet Propulsion Laboratory, and a commercially available system is being manufactured by Advanced Semiconductor Materials Laboratory in Phoenix, Arizona. The JPL laser scanning system appeared to have favorable prospects. Its potential optimization, however, and its practicality for production line applications requires further study. The ASM laser scanning system is available for production applications and was found to be the most suitable scanning technique of the three methods considered.

An indepth analysis was made of the ASM Automatic Surface Inspection System (ASIS) in order to accurately assess its feasibility for use in production line applications. In this capacity, samples of silicon solar cells with nickel metallization and solder, and also nickel metallization without solder on texturized and untexturized cells were provided for the performance verification tests of the ASIS equipment. The primary objectives of the performance verification tests were as follows:

- Detection of micro-cracks.
- Detection of floating metal.
- Detection of breaks in metallization which develop during the plating process.
- Detection of saw damage.
- Detection of soldering defects.

The current equipment is designed specifically for the inspection of 3" diameter wafers, but with the incorporation of minor equipment modifications, its range of applicability can be extended to 90 mm diameter wafers.

The ASM Automatic Surface Inspection System (ASIS) is an MPU-controlled system that quantitatively measures the defect level present on a highly reflective surface. Primarily designed for application in the semiconductor industry, the ASIS system can automatically monitor critical processing steps.

During the course of experimental studies, it was shown for polished surfaces that major cracks greater than 15 mils, saw damage, and fingerprints could all be easily detected. Due to the inherent resolution limitations of the laser beam, micro-cracks, floating metal, and poor solder contacts were all undetectable. This same line of reasoning will apply equally well to texturized surfaces with the one exception of fingerprint detection which is precluded as a result of the discontinuity of the fingerprint pattern over the pyramidal surface structure of the texturized solar cell.

The laser beam size, which is currently 15 mils wide, has been determined to be the major limiting factor with regard to the ultimate diversity in application of the ASIS equipment. This conclusion is a consequence of the inherent resolution limitations of the laser beam. The ASIS system, as it is currently configured, will not meet our requirements. However, it is expected that with the incorporation of suitable equipment modifications, the ASIS system could offer excellent prospects.

A cost estimate was made for the ASM Automatic Surface Inspection System for the purpose of establishing its cost effectiveness. The throughput of the ASIS system is currently 900 wafers/hr., which falls short of the projected 1986 pricing goals. This figure can, however, be significantly enhanced by utilizing a multitrack system. The resulting process cost corresponding to the ASM system was found to be 0.941 cents/watt in terms of 1980 dollars, which is low enough to ensure its feasibility for usage in an automated assembly line.

In conclusion, the ASM ASIS system has a potential for use in the inspection of mechanical defects in solar cells in view of process cost. However, it will require further development effort to detect all the types of cracks in the solar cells.

O. Cell Handling for Module Construction

Cell handling for module construction will require precision positioning techniques in addition to an approximate rate of 2 cells/second if the module construction line is to produce 7200 wafers/hr. or 60 modules/hr. in accordance with 1986 production goals.

Several varieties of solar cell handling units are available from semiconductor industries and most of them are designed to fit a particular application. For example, the printing machine industry uses cassette-to= conveyor loading which requires a specialized cell positioning system.

A precision positioning system used throughout the semiconductor industry is the robot arm, which unfortunately operates at a slow rate. This rate is primarily dependent upon the number of degrees of freedom required to locate an object and usually exceeds 2 sec./cycle.

An alternative cell positioning technique makes use of a hopper dispenser unit. This system has the advantage of being able to simultaneously dispense several cells, thereby permitting a choice of cycle times and/or production rates. However, the hopper dispenser unit is unable to deposit cells within a close enough proximity such that the gap between cells is approximately 50 mils. Since this method does not display the precision positioning capability characteristic of the robot arm, it was determined to be unsuitable for our requirements. Consequently, a conceptual design for a robot arm system with multiple pick-up heads was devised. This appears to hold promise in meeting 1986 production goals.

The module which is to be constructed by the robot arm system with multiple pick-up arms will contain six full cells and two half cells per row, with each alternating row maintaining the same sequential cell arrangement.

The conceptual drawing of the solar cell handling system is shown in Figure 25. Two robot arms will each simultaneously deposit the six full cells and two half cells which are placed in a prearranged pattern on their respective cell storage racks.

This system will deposit a total of 16 cells per cycle with good pattern reproducibility. The required cycle time will be six seconds and the conveyor will move by two rows during each cycle.

The technology for fabricating the robot arm system with multiple pick-up heads is well developed, and consequently, this robot arm system is recommended for use in the 1986 array automated assembly system.

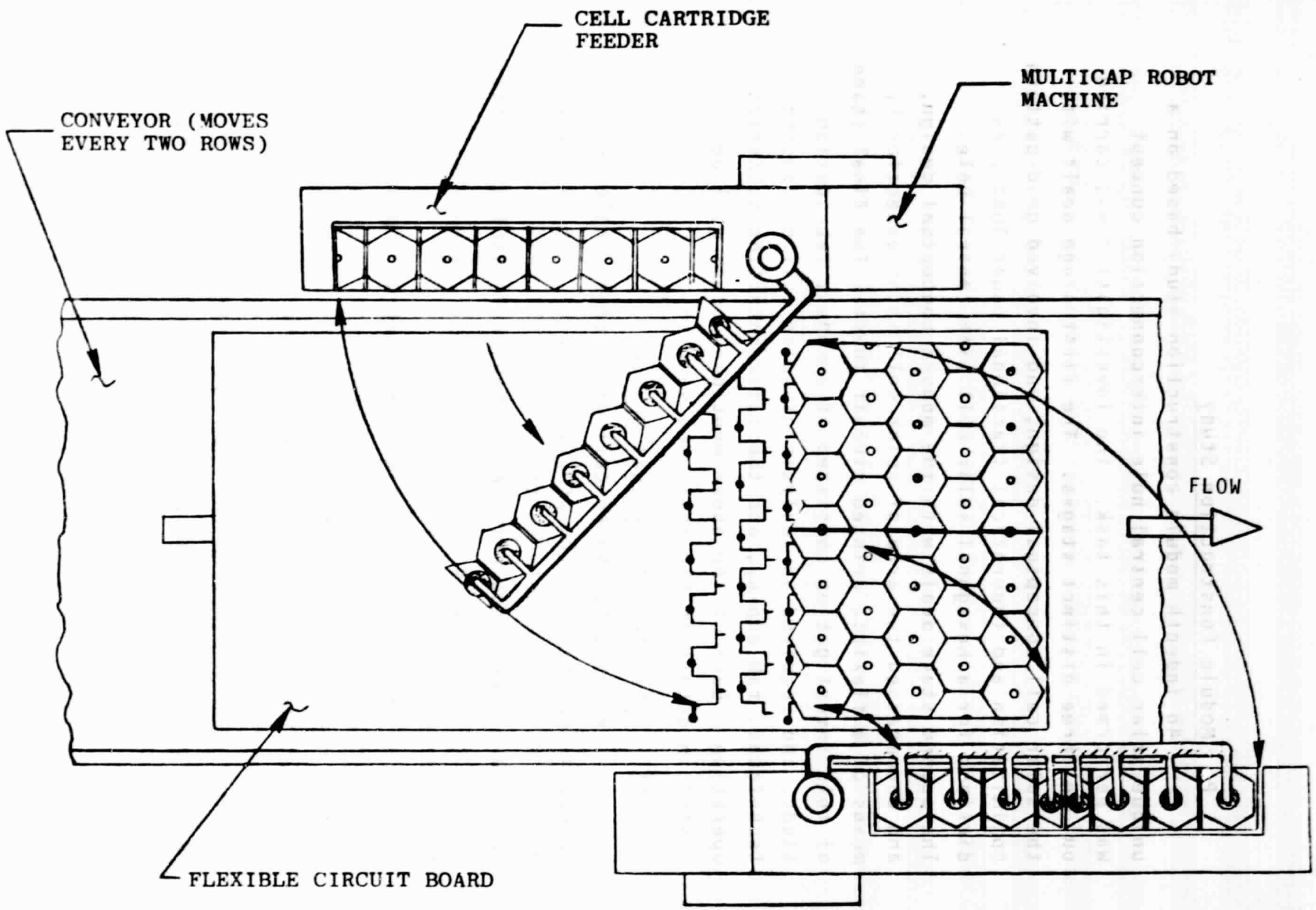


Figure 25. Conceptual Drawing of Cell Handling System for Automatic Module Assembly Line.

P. Module Construction Study

An indepth module construction study based on a unique solar cell central hole interconnection concept was performed in this task. The investigation was carried out in three distinct stages. The first stage dealt with the solar cell conceptual design, and involved grid pattern optimization and theoretical fractional power loss predictions for a hexagonal solar cell with central hole. The second stage dealt with the module conceptual design, and encompassed the area of solar cell interconnection by means of a flexible printed circuit sheet. The final stage of this investigation consisted of a module fabrication study, and required an analysis of solar cell dispensing techniques, tab pop-up, and the interconnection soldering operation. Each of the above mentioned areas will be discussed in detail in the following sections.

P1. Solar Cell Conceptual Design

A hexagonal solar cell with central hole was selected for usage in the proposed module. The most pronounced difference between this solar cell design and the solar cell then being produced by Sensor Technology is the new central hole current collection method as opposed to the edge current collection method.

The new solar cell was fabricated from 3.54 inch (90 mm) diameter silicon wafers. Hexagonally shaped wafers with point-to-point diameters of 3.54 inches and central hole diameters of 0.150 inches were formed by means of an automated laserscribe. The solar cell gridline pattern was designed to minimize the combined effect of the shadowing and ohmic loss components. The ohmic power loss encompasses both the diffusion layer ohmic loss and metal gridline ohmic loss.

The gridline pattern optimization was calculated according to the following specifications.

(a) The gridline width was fixed at 7 mils which was the technological limit imposed by the thick film printing equipment.

(b) Each gridline was separated by equal areas which resulted in an equal current flow into each gridline.

(c) The trunk-line was extended through the center of each triangular area which permitted the cell to be cut through any diagonal, thus preparing the cell for placement in the module.

(d) The approximate values of the resistivities used in the various power loss calculations are as follows:

Diffusion layer resistivity: 30 $\Omega/\square$
Gridline sheet resistivity: 0.004$\Omega/\square$
Trunkline sheet resistivity: 0.001$\Omega/\square$

(e) Current density was assumed to be 32.5 mA/cm^2 and the voltage at the maximum load was assumed to be 0.5 volts.

Upon utilizing the above assumptions, it was found that the optimum number of gridlines should be seven for the hexagonal solar cell with central hole. The optimized gridline pattern is presented in Figures 26 and 27.

The calculated results for the fractional power loss of each element of the hexagonal solar cell with central hole are presented in Table 20. It is evident from the table that the larger contributing element to the total fractional power loss resides with the gridline shadowing power loss.

Theoretical analysis shows that the fractional power loss can be improved by as much as two to three percent by reducing the width of the gridlines. This is due to the fact that the ohmic loss for our solar cell gridlines is very small. The solar cell gridlines, unfortunately,

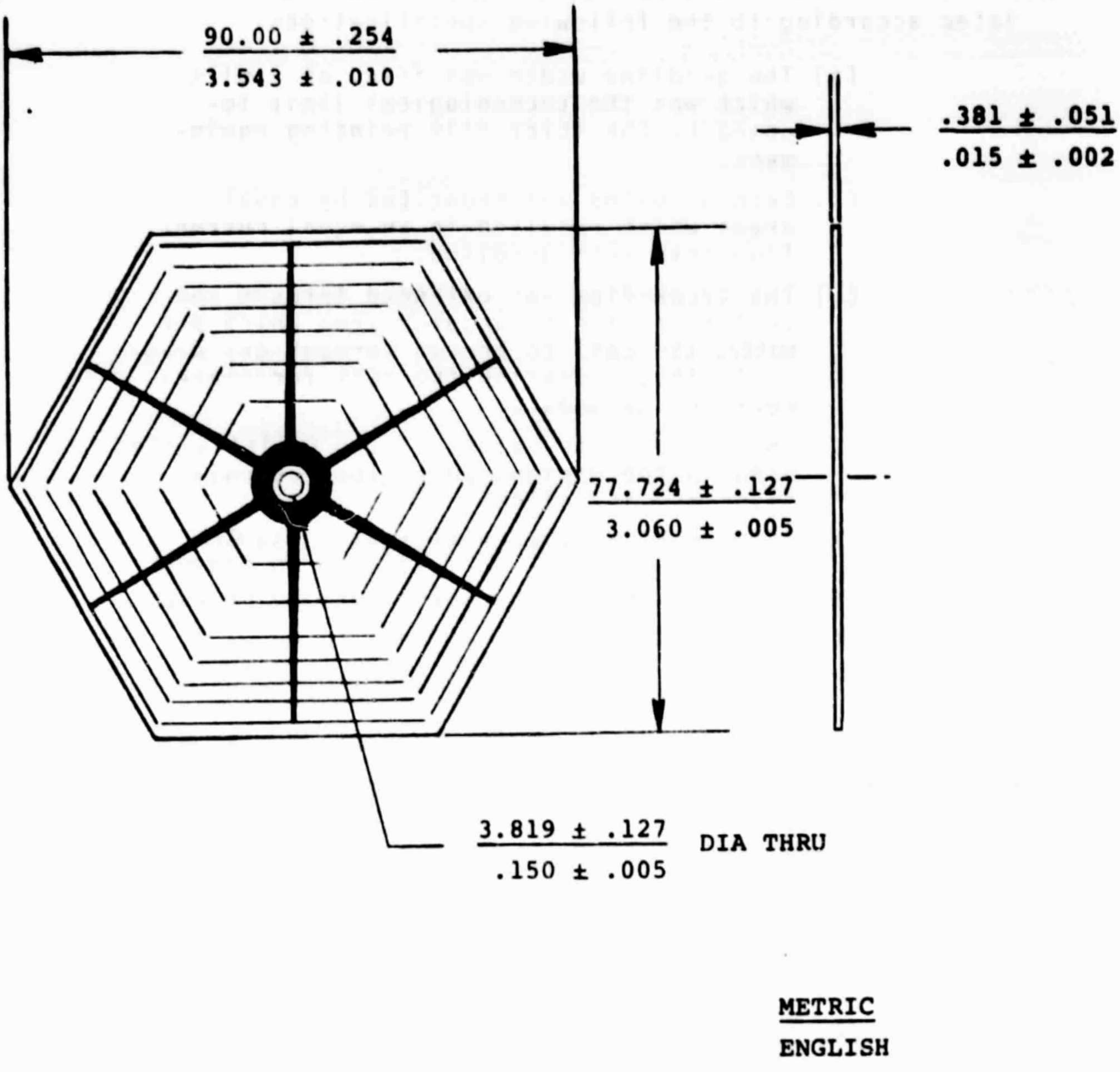


Figure 26. Hexagonal Solar Cell with Central Hole.

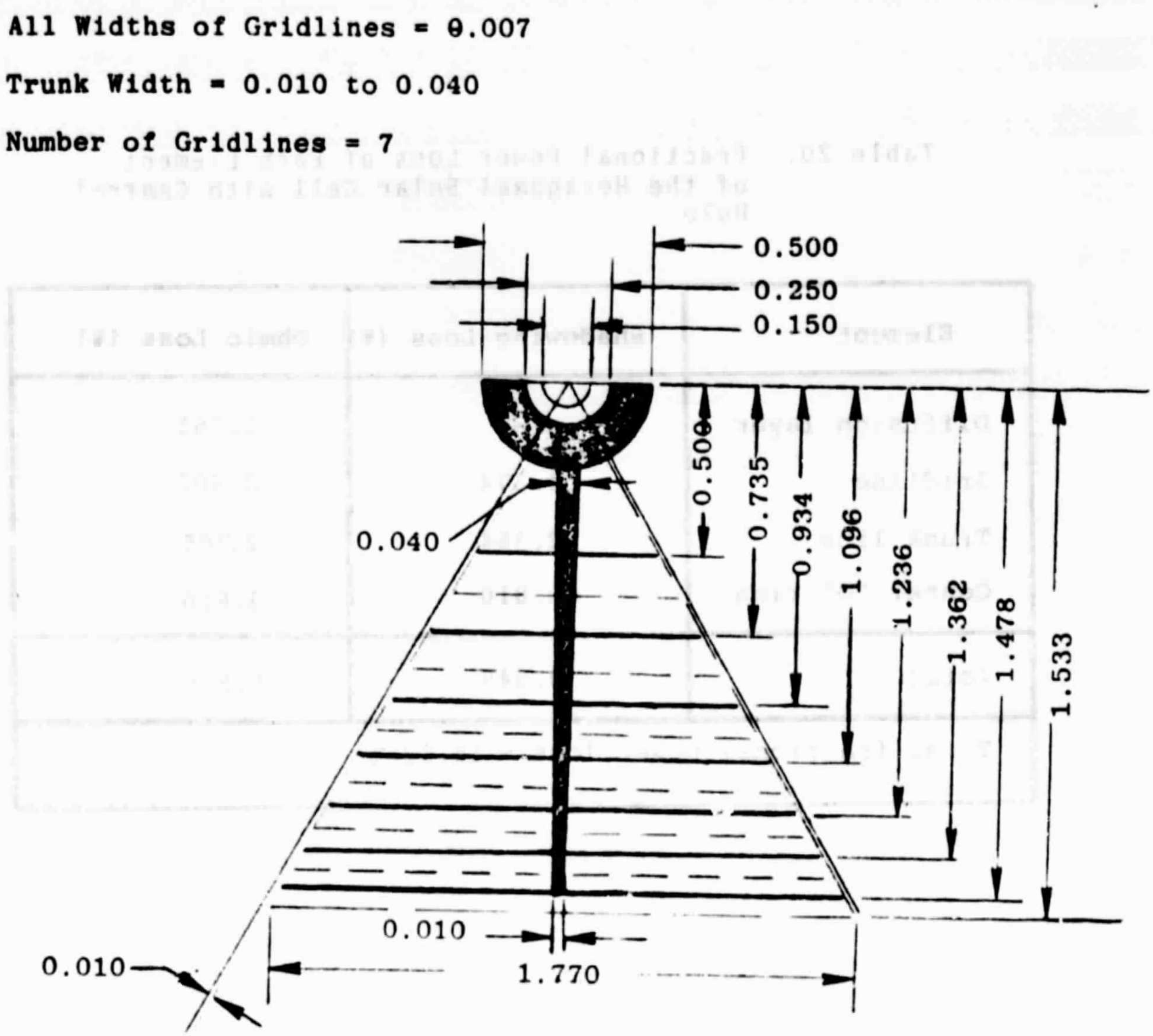


Figure 27. Hexagonal Solar Cell Grid Pattern with Central Hole.

Table 20. Fractional Power Loss of Each Element of the Hexagonal Solar Cell with Central Hole.

Element	Shadowing Loss (%)	Ohmic Loss (%)
Diffusion layer	--	2.761
Gridline	4.374	0.402
Trunk line	2.364	2.205
Center "O" ring	1.810	1.610
Total	8.548	6.978
Total fractional power loss = 15.526%		

could only be reduced to a certain width, subject to the constraints imposed by the technological limits of the then current thick film printing equipment. Improvements in this field will allow modifications to occur in the future.

A second alternative is to decrease the number of gridlines on the solar cell. However, by decreasing the number of gridlines from, for example, seven to six, the total fractional power loss increased to 15.90%. This fractional power loss occurred because the shadow reduction due to less gridlines was not sufficient to compensate for the increase in ohmic power loss. Calculations also show that the number of gridlines and the gridline patterns are relatively insensitive for an optimized amount of shadowing on a solar cell.

The final solar cell design feature considered in this study was the "O" ring contact line which exhibited a fairly large shadowing loss and a small ohmic power loss. This situation cannot be easily rectified since tab soldering requires a finite area.

P2. Module Conceptual Design

The module conceptual design for 1986 consists of 119 hexagonal solar cells. The packing arrangement of 102 full solar cells and 34 half solar cells in the 2 ft. x 4 ft. module is exemplified in Figure 28, where the spacing between the cells is 0.05 inches, the solar cell area is 968.65 in.^{2}, the solar cell nesting area is 1030.58 in.^{2} and the module area is 1113.09 in.^{2}. The module packing efficiency was determined to be 87% and the solar cell nesting efficiency was found to be 94%.

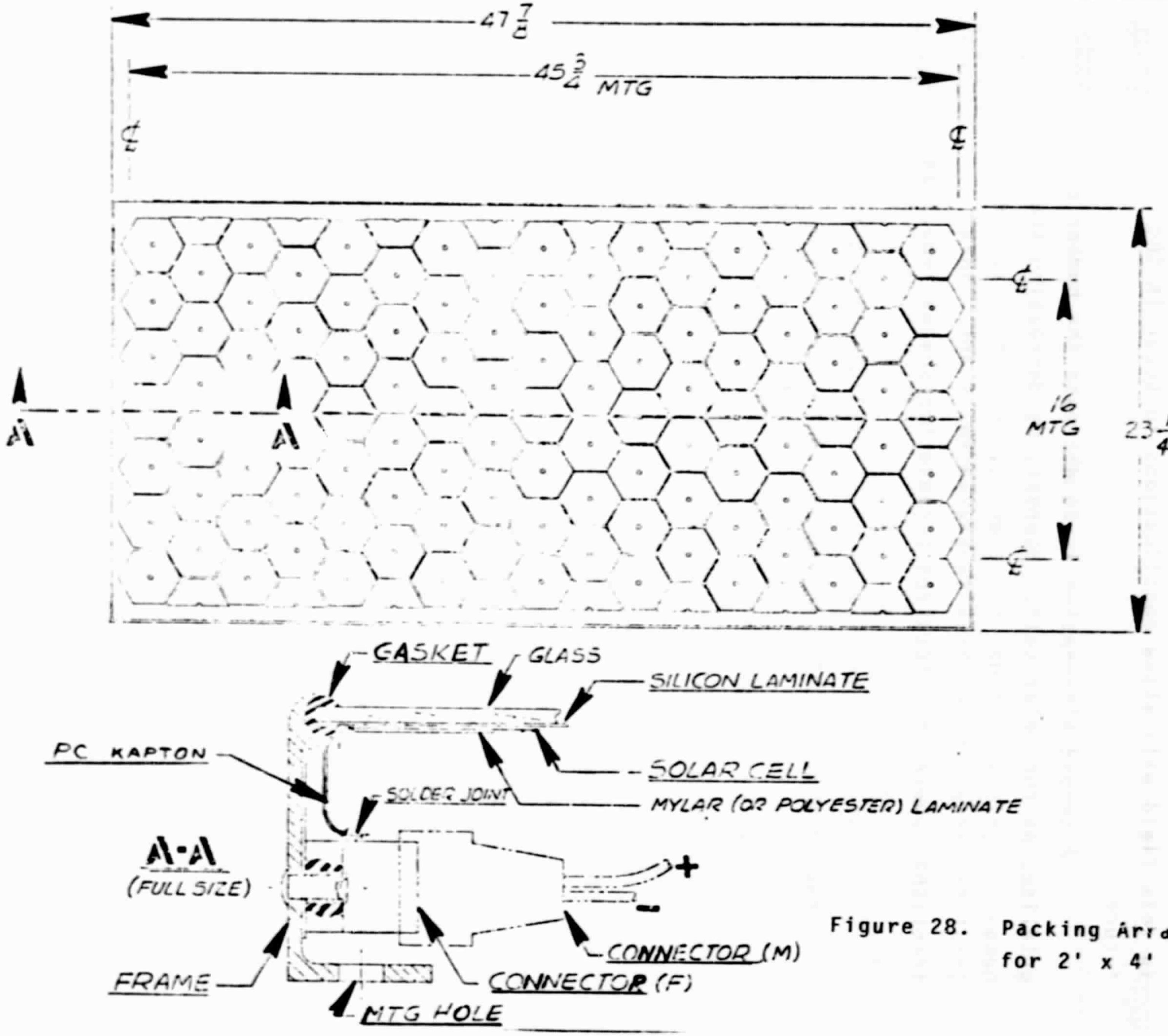


Figure 28. Packing Arrangement for 2' x 4' Module.

Figure 28. Packing Arrangement for 2' x 4' Module.

In order to minimize the potential electrical power loss due to solar cell failure, a group of three full hexagonal solar cells and one-half solar cell shall be connected in parallel and thirty-four groups shall be connected in series. The encapsulated solar cell efficiency shall be 14.5% with a peak power output of 0.76 watts. The expected module electrical performance at 100 mW/cm^2 and at $28^{o}C$ shall be as follows:

90 watts at peak power
17.14 volts at peak power
5.25 amps at peak power

All solar cell interconnections in the module conceptual design shall be achieved by means of a flexible printed circuit sheet. The flexible printed circuit sheet conceptual design is shown in Figure 29. Two ounces of copper per sq. ft. is a good guide for typical PC sheets. The copper would be about 3.0 mils thick. This thickness is variable and could be adjusted to specification. The sheet configuration could use either a single or double clad design.

A single clad design was found to substantially reduce the cost of the PC sheet and is the preferred configuration. The single clad flexible printed circuit sheet was designed to minimize thermal stress. The PC sheet will allow for connection from the bottom of one solar cell through the central hole, to the top of an adjacent solar cell as shown in Figure 30.

The flexible PC sheet has tab cutouts which allow the tabs to be pushed up by a plunger to thread the solar cell. When the plunger is removed the tab makes contact with the center solder ring of the solar cell. Holes 2.125 inches in diameter are also cut out of the flexible printed circuit sheet which will allow for total lamination from the front of the module through the sides of the solar cells to the back of the module.

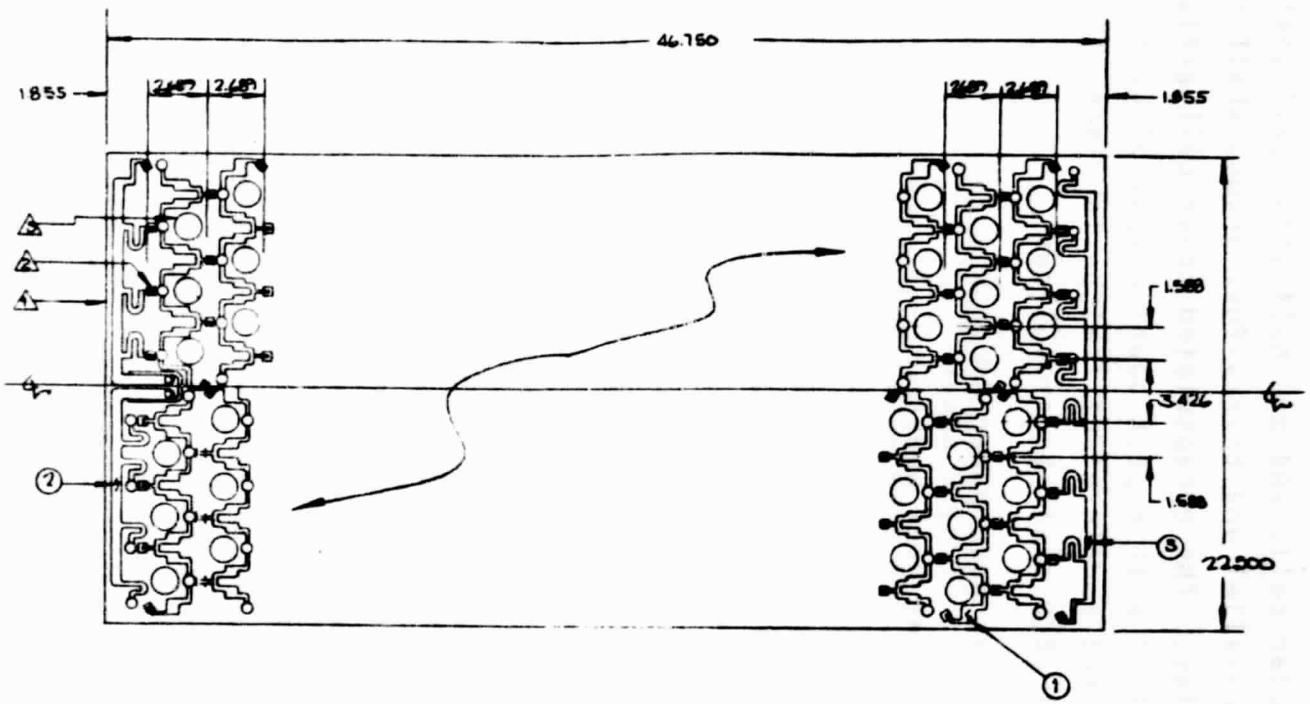


Figure 29. Cell String Flex Circuit for the 2' x 4' Module.

3. 2.125 DIA. CUT OUT
2. TAB CUT OUT
1. USE 3 MILES KAPTON (OR MYLAR) SHEET CLADDED BY 2 OZ. PER SQUARE FT. OF COPPER.
NOTES: UNLESS OTHERWISE SPECIFIED

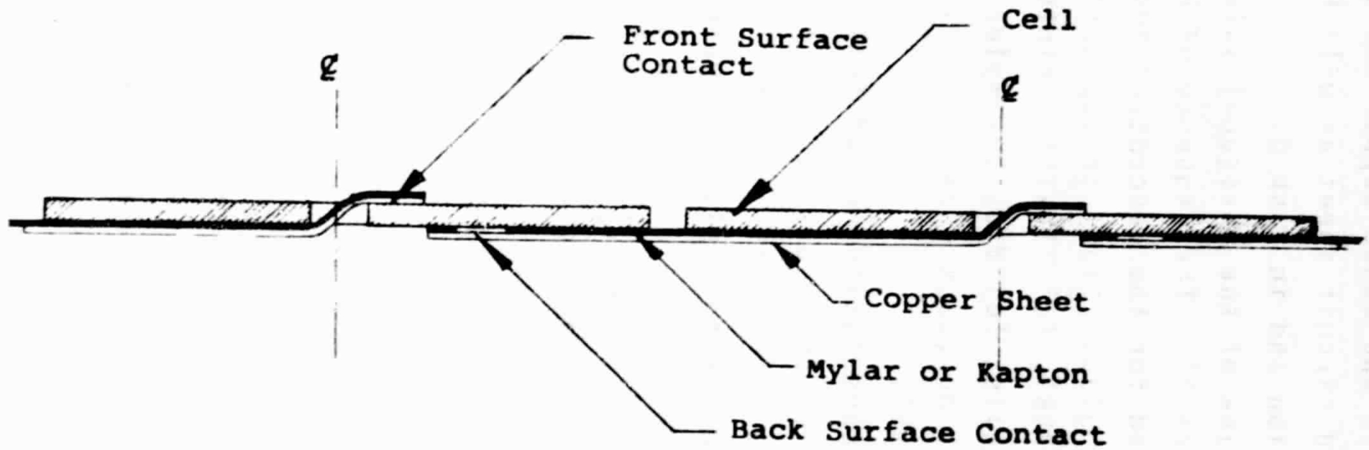


Figure 30. Interconnection Method Between Cells (Copper Clad Kapton Sheet without Overlay)

Two types of PC sheet materials were studied. Both Kapton and Mylar are potential candidate materials. One mil thick Kapton with two ounce copper was chosen for the flexible printed circuit sheet as will be discussed in the next section and in Task Q.

An exploded view of the hexagonal solar cell module is shown in Figure 31. The sequence of encapsulation materials utilized for the conceptual module design is as follows: (a) glass (front or top surface), (b) polyvinyl butyral (PVB), (c) flexible printed circuit sheet with solar cells, (d) PVB, (e) Mylar with moisture protective coating (back surface), (f) gasket and aluminum frame assembly.

The module encapsulation method followed the standard SAFLEX lamination procedure as then currently performed throughout the auto-glass industry. The only modification needed in order to apply this method to solar cell modules was to utilize a vacuum bag procedure. The sequential steps incorporated within this encapsulation technique include: (1) washing dusted SAFLEX, (2) material lay-up, (3) degassing and vacuum bagging, (4) curing, (5) trimming and frame assembly.

P3. Module Fabrication Study

An experimental investigation was performed in three areas of module fabrication. This work included a study of solar cell dispensing techniques, a tab "pop-up" scheme to allow solar cells to be dropped into position on a flexible printed circuit sheet and a solar cell interconnection soldering operation on a flexible printed circuit sheet.

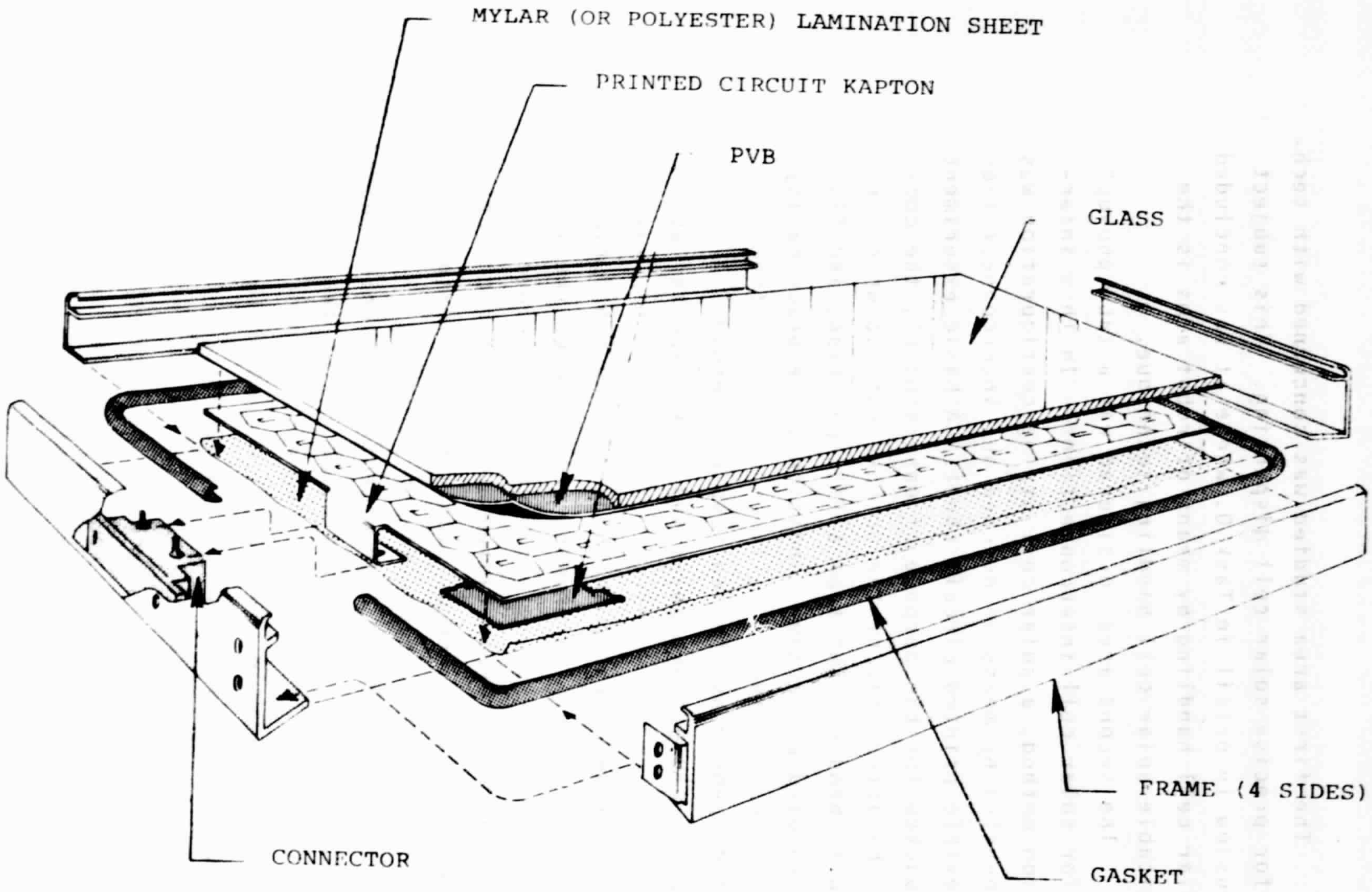


Figure 31. Exploded View of Hexagonal Solar Cell Module.

The first area studied was concerned with techniques for precise solar cell dispensing. This subject is discussed in detail in Task 0, where it was concluded that solar cell handling by means of robot arms is the most suitable solar cell handling technique.

The second area considered was a tab "pop-up" scheme for solar cell interconnections. In this interconnection method, a solar cell string configuration was interconnected by means of notched out interconnect tabs on a flexible printed circuit sheet. A basic experiment was conducted for the purpose of observing (1) the compliance characteristic of the notched-out tab when constrained to bend upright from a flat position, and (2) under simulated production conditions, the practicality of interconnecting individually dropped cells from an overhead dispenser by the tab "pop-up" method. A single "pop-up" plunger mechanism and cell dispenser were fabricated and manually tested. The plunger pin was modified to include a groove which guided the tab during the push up motion. This experiment demonstrated the viability of the tab "pop-up" interconnection technique.

The third area studied was the interconnection soldering operation. The utilization of a flexible printed circuit sheet requires simultaneous soldering of both the front and back contacts. Four potential soldering methods for performing the simultaneous soldering of the front and back contacts were identified. These four soldering methods are: (1) induction soldering, (2) I.R. soldering, (3) direct soldering, and (4) flameless gas soldering.

Induction soldering and I.R. soldering are both widely used procedures for producing simultaneous multiconnections. Unfortunately, however, neither method appears to be applicable to solar cells containing soldered gridlines,

since reflow of solder from the gridlines will damage the metal contacts, which in turn will adversely affect the solar cell efficiency. Therefore, the investigation focused on the direct and flameless gas soldering methods.

A direct contact soldering test on a flexible printed circuit sheet was performed with the primary objective of evaluating three prospective materials for use as a base material in the flexible PC sheet, and then selecting from these, that material which displays the most acceptable chracteristics.

The three materials which were evaluated are as follows:

K1 = 1 mil Kapton with 2 oz. Cu
K2 = 2 mil Kapton with 2 oz. Cu
K3 = 3 mil Mylar with 2 oz. Cu

A highly skilled operator performed the actual soldering task with the use of a controlled tip, hand-held soldering iron at a temperature of 700^{0}F. The entire soldering sequence was precisely timed and the following results were subsequently obtained:

K1: Time - 4 sec., no damage to Kapton-satisfactory

K2: Time - 10 sec., no damage to Kapton-solder deposit melt

K3: Time - 4 sec., Mylar melts-good soldering

Direct contact soldering was found to be completely ineffectual with regard to melting solder on material type K2. On the other hand, the soldering characteristics of material type K1 were found to be adequate. Due to its low melting point, the Mylar material had melted prior to the solder. Back surface contact soldering produced poor results for each material. Consequently, a more accurate and intense heat source was required for accomplishing contact soldering.

The alternative method of flameless inert gas soldering was investigated in order to determine its applicability for use in conjunction with a specified base material for the flexible PC sheet. The flameless heating unit studied offers extremely precise temperature control for production soldering, brazing, bonding, curing or melting at temperatures up to 1600°F. The heater consists of a tungsten filament inside a quartz tube over which air or inert gasses such as argon or nitrogen are passed. The coil design provides extremely efficient energy transfer which permits non-contact heating of parts in open or confined areas. Controls permit regulation of gas flow, pressure, and electrical input into the heater thus allowing pin-point repeatable heat control.

The following experiments were performed with this equipment:

- Front surface contact soldering.
- Back surface contact soldering.
- Soldering cell to a 2 oz. copper-Kapton sheet.

All experimental results proved to be extremely satisfactory and this method is therefore recommended for use in the solar cell interconnection soldering operation.

Q. Module Model Fabrication Study

A unique hexagonal solar cell central hole interconnection concept involving the use of a flexible printed circuit sheet with notched-out tabs, and a PVB lamination procedure for module encapsulation, was demonstrated with the fabrication of a module model. The novel solar cell interconnection concept was found to greatly simplify the cumbersome task of solar cell interconnection for cell string assembly.

The demonstration of the PVB lamination procedure required a determination of important process parameters such as the time, pressure and temperature cycles required for the optimal performance of the lamination procedure. An important facet of the demonstration of the PVB lamination procedure resided in verifying that hexagonal solar cells with central holes can withstand the lamination procedure without incurring excessive damage due to radial cracks.

Since the viability of the flexible printed circuit sheet with notched out tabs is described in detail in Task P, the demonstration of the lamination procedure and module assembly process will receive major emphasis in the following sections.

Q1. Decription of the Module Model

A module model consisting of hexagonal solar cells interconnected through their central holes by way of notched-out tabs on a flexible printed circuit sheet was fabricated through the use of a PVB lamination process.

A picture of the hexagonal solar cell module is shown in Figure 32. The dimensions of the module are 12" x 15". All other aspects of the module model are identical to the large scale prototype module described in Task P, with the exception of the number of hexagonal solar cells.

The flexible printed circuit sheet for the module model is shown in Figure 33. As can be seen from this figure, 3½ cells are connected in parallel, and five such cell strings are connected in series so that the total number of cells is equivalent to 17.5 full hexagonal solar cells (15 full cells and 5 half cells).

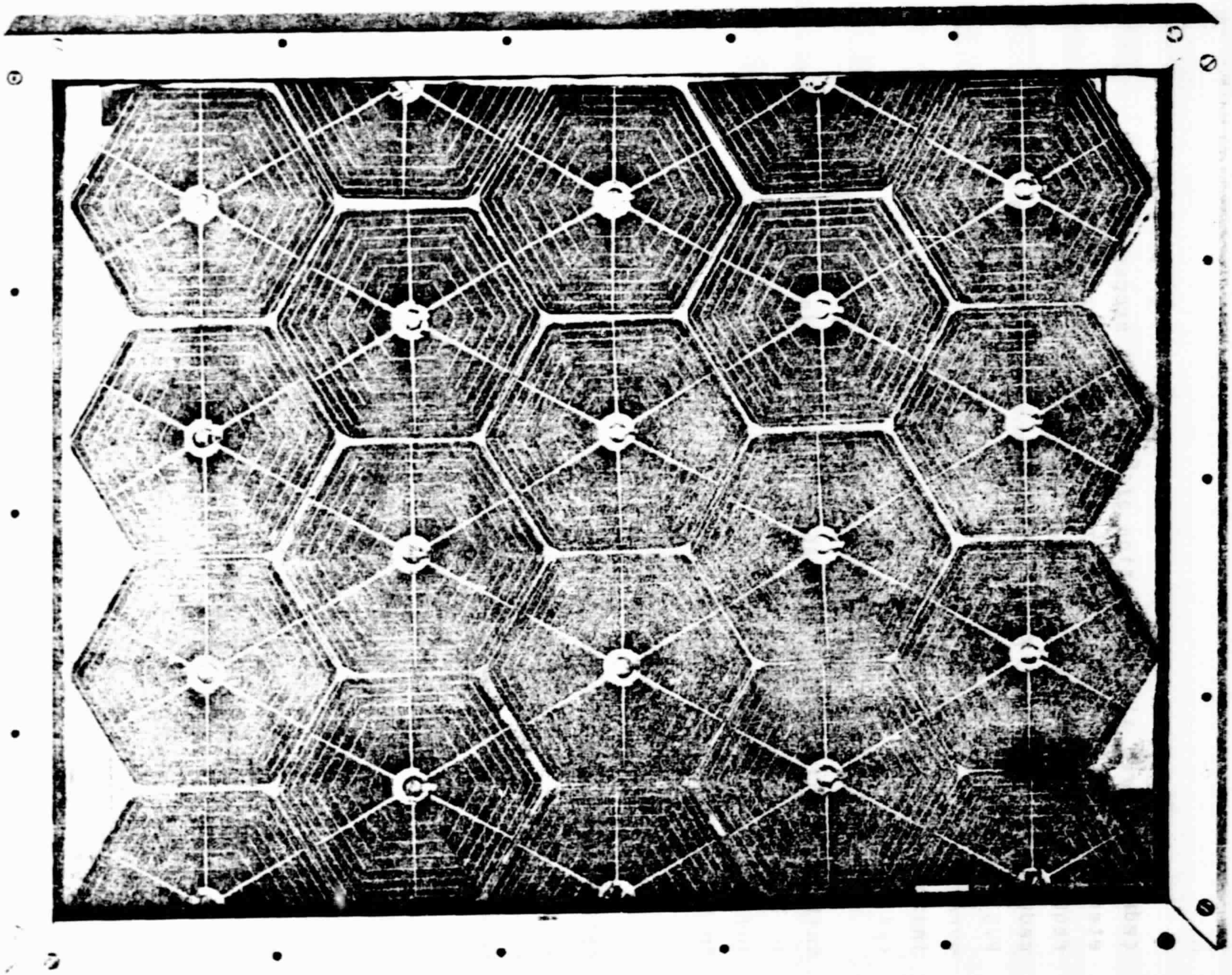


Figure 32. Picture of the Hexagonal Solar Cell Module with Center Hole Interconnection Scheme.

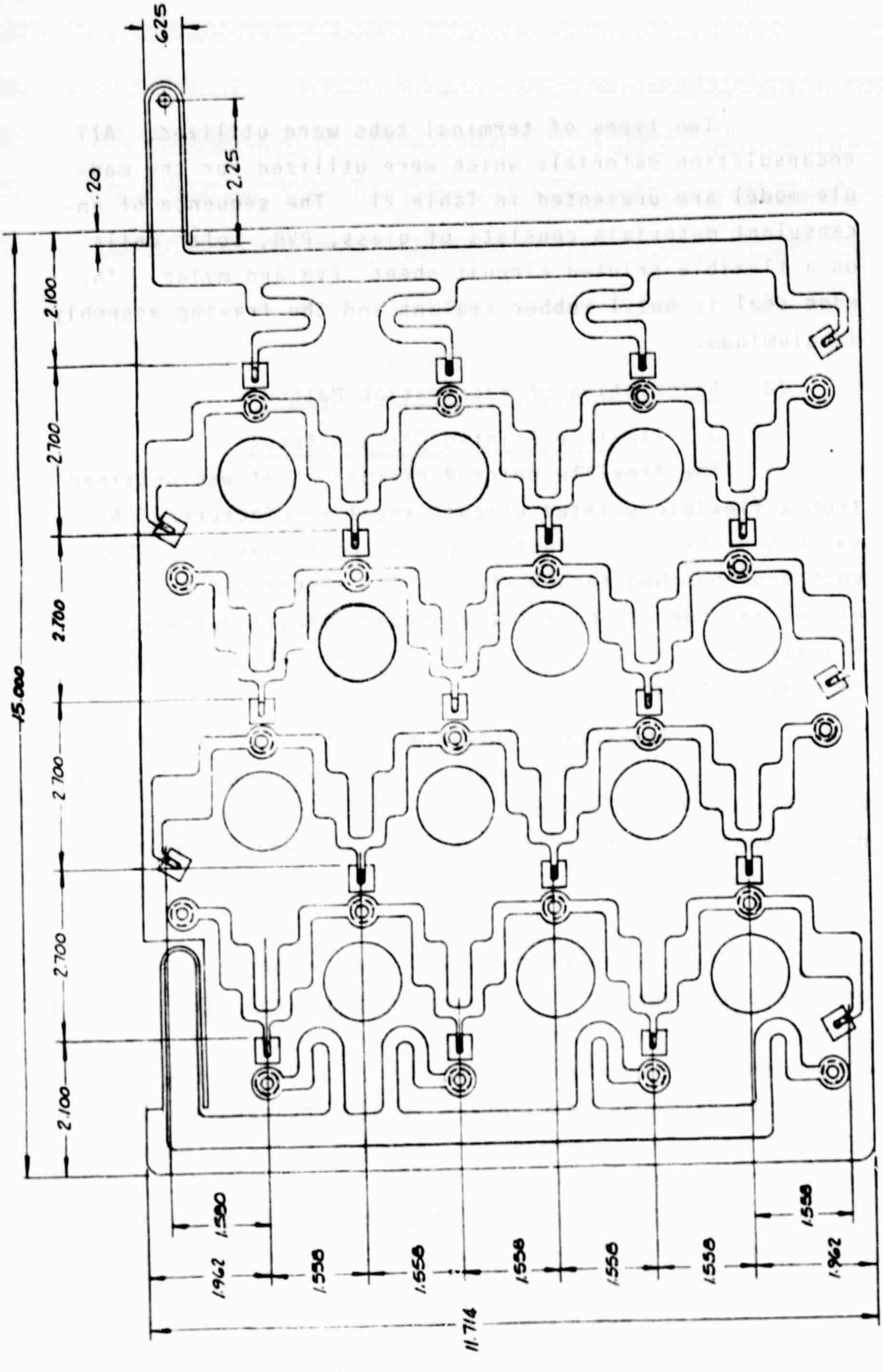


Figure 33. Cell String Flex Circuit Model Configuration.

Two types of terminal tabs were utilized. All encapsulation materials which were utilized for the module model are presented in Table 21. The sequence of encapsulant materials consists of glass, PVB, solar cells on a flexible printed circuit sheet, PVB and mylar. The edge seal is butyl rubber sealant and the framing assembly is aluminum.

Q2. Description of Fabrication Method

a. Flexible Printed Circuit Sheet

The flexible printed circuit sheet was obtained from a flexible printed circuit sheet manufacturer. A two ounce per square foot sheet of copper was laminated onto a prepunched Kapton sheet. The copper was then etched in order to obtain the proper circuit pattern. Finally, the tab for central hole solar cell interconnection was cut out.

b. Solar Cell Interconnection

The cells with central holes were positioned and manually soldered by means of the flameless inert gas soldering method. The cells were then prepared for the lamination procedure.

c. Encapsulation

The standard PVB lamination procedure is currently practiced throughout the auto-glass industry. The only modification which was necessary in order to apply this method to photovoltaic modules was the use of a vacuum bag method. The design dependent parameters such as temperature and pressure were determined experimentally and will be discussed in a later section.

A brief description of each step incorporated within this encapsulation technique is presented below.

Table 21. Final Encapsulant Materials for Module Element.

Elements	Selected Materials
Superstrate:	ASG SUNADEX (rolled water white, 0.019 iron oxide), glass, tempered, 1/8" thick.
Flexible Circuits:	0.001" Kapton with 2 oz/sq.ft. copper laminated.
Adhesive Material:	SAFLEX SR11 (architectural type) 0.015 in. thick. Two layers of this type are needed at top and bottom of cell strings.
Substrate:	Mylar type "A", 0.005" thick.
Edge Sealant:	Butyl rubber sealant (TREMCO PROGLAZE with TREMCO ARO-SHIM).
Frame:	Aluminum frame, anodized.

Washing Dusted Saflex - Dusted Saflex, which is PVB with a coating of sodium bicarbonate interleaved to prevent sticking, must have the sodium bicarbonate removed by washing in 110^{o} to $120^{o}F$ water and rinsing.

Lay-up - All layers are put in lay-up form in order to facilitate encapsulation. The layered structure consists of glass/PVB/cell string assembly/PVB/mylar. Each sheet must be cleaned prior to lay-up, and the lay-up takes place in a temperature and moisture controlled room.

Degassing and Vacuum Bagging - All layers are placed into the vacuum chamber with heat sealable nylon at the top and bottom of the structure. The chamber is gradually heated up to 165^{o} to $265^{o}F$ while it undergoes concurrent degassing with the vacuum pump. The chamber is then pressurized at approximately 15 to 50 psig, and the vacuum bag is sealed.

Autoclaving - The autoclaving operation is the final step in the laminating process. The vacuum bagged module layers are heated up to a temperature range of 250^{o} to $300^{o}F$. The entire assembly is then pressurized at 50 to 180 psig and held for 7 to 30 minutes. After this holding period, it is slowly cooled down to $160^{o}F$ while under pressure. The pressure is then released.

The key parameters for this operation are temperature, holding time and pressure. In particular, if the gridlines contain solder, the maximum temperature must be less than the melting point of solder in order to prevent solder reflow. In addition, the pressure must be as small as possible to prevent cell cracking due to pressure loads.

All parameters are dependent upon lamination size, thickness and number of layers. Consequently, these parameters must be determined experimentally for the conditions present in each different panel fabrication house.

d. Framing Assembly

The excess sheet material at the edges of the encapsulated modules was trimmed off. The aluminum frame was then mounted with the proper sealant.

03. Experimental Study

Four progressive tests were performed to determine the proper laminating conditions. A reference module (B-2) with "parallel track" pattern hexagonal solar cells without a PC sheet was used to elicit a comparative analysis. The test conditions in all four cases are summarized in Table 22. A summary of the results of each test is presented in Table 23. The test results are summarized in the following sections.

Test #1 - For the initial test, the highest possible temperature (356°C) and the highest possible pressure (50 psi) were chosen in conformance with the previously designated process parameter limitations. The test results indicate that many cracks developed within the central hole solder ring. In addition, there was evidence of solder reflow caused by the high temperature. Despite the fact that 90% of the cells were cracked, there was no indication that this had a deleterious effect on the module electrical performance as evidenced by Table 23. The negligible effect of the cracked cells on the module performance can be explained on the basis that since the cracks occurred within the center ring, they have no influence on current collection outside of the ring.

Test #2 - To eliminate the solder reflow problem observed in Test #1, the temperature was reduced to 347°F and also a thicker PVB sheet (30 mil) was utilized to prevent interior center ring cracks induced by the thick solder layer at the center ring.

Table 22. Summary of the Test Conditions for the Module Model Fabrication.

Test No.	Top PVB Thickness	Autoclave Temp.	Autoclave Pressure	Total Process Time
A-1	15 mils	356°F	50 psig	2 hours
A-2	30 mils	347°F	50 psig	2 hours
A-3	30 mils	270°F	50 psig	4 hours
A-4	30 mils	270°F	45 psig	4 hours
Ref. (B-2)	15 mils	347°F	50 psig	2 hours

Table 23. Summary of the Electrical Performance Test Results for the Module Model Fabrication.

Test No.	Voc*	Isc*	Description of Results
A-1	2.89 volt	4.16 amp	90% of cell has hole ring cracks. Solder reflow. Bubble at center hole.
A-2	2.87 volt	4.6 amp	50% of cell has ring cracks. Bubble at center hole. No solder reflow.
A-3	2.65 volt	4.15 amp	Three line cracks. No bubble. No solder reflow.
A-4	2.85 volt	4.29 amp	One line crack. No bubble No solder reflow.
Ref. (B-2)	2.89 volt	4.24 amp	No cracks. No bubbles

*Test at 28°C, 100 mW/cm² insolation

The results show that 50% of the cells still have interior center ring cracks. However, the solder reflow problem was eliminated. The module electrical performance was similar to Test #1. Bubbles were also trapped in the front surface.

Test #3 - This test was distinguished by lower temperature (270^{0}F) and longer heating cycles with the same pressure load. The longer heating cycle served to ensure uniform heating prior to pressurization. The results showed an apparent improvement. No center ring cracks were observed; however, three cells had line cracks. The electrical performance of this module was almost identical to the reference module.

Test #4 - This test was identical to Test #3 except that a slightly lower pressure was utilized. This time, only one line crack was observed. However, it is believed that this crack was introduced, during lay-up, from mishandling. The electrical performance of this module was found to be higher than the others tested.

Test #5 - The "parallel track" pattern hexagonal solar cell module without central holes (B-2) incurred no encapsulation problems based on past experience. The sequence of encapsulation materials was glass/PVB/cell string/PVB/Mylar. Back solar cell interconnection was achieved by two ribbon wires. Three- and one-half cells were interconnected in parallel and five such groups were connected in series. The encapsulated module was bubble and crack free. This module type was used as a reference module for comparison to the test modules.

Discussion of Test Results

The module model which utilized the central hole interconnection method with a flexible printed circuit sheet was successfully encapsulated with PVB adhesive as the underlayer. The module model fabrication required the specification of several process parameters due to the thick solder layer at the center hole and the stress concentration at the center hole. In comparison with conventional (reference) module fabrication, it can be concluded that:

- The new module requires more processing time due to the longer heating cycle.
- The new module requires low temperature during fabrication.
- The new module displays good electrical characteristics if a thick layer of PVB is utilized.

An extensive experimental study could possibly reduce the processing time. Since the processing parameters were dependent upon the module size, no further study was performed with the small scale module. It was demonstrated that the new fabrication concept is feasible, and further study with a prototype scale module to optimize fabrication parameters is recommended but was beyond the scope of this contract.

Q4. Module Model Fabrication Conclusion

The specification of several process parameters led to the successful performance of the lamination procedure for the module model. The central hole interconnection scheme was successfully demonstrated; no solar cell cracks were observed after the proper lamination procedure was evolved. It was found that this central hole interconnection method greatly simplifies solar cell string assembly for module fabrication.

R. Cell Test Data Acquisition

Photowatt International presently utilizes a solar cell module test data acquisition system to measure and record the electrical performance under a pulsed Xenon solar simulator for large scale production contracts. This system automatically samples the module electrical performance and plots the I-V characteristic curve on an X-Y plotter.

A design modification of our electronic equipment was undertaken for the purpose of demonstrating that a single solar cell can be automatically tested and its electrical performance recorded. A sketch of the test equipment is shown in Figure 34. The complete system consists of a pulsed Xenon light tower, a temperature controlled solar cell mounting block with reference cell, an automatic solar cell test data acquisition system, and an X-Y plotter. The equipment demonstrated the capability of measuring the electrical performance of solar cells for use in evaluation of solar cell quality and suitability for module assembly.

The cell test data acquisition system samples the Xenon solar simulator at 100 mW/cm^2, and automatically records the solar cell short circuit current (I_{sc}), open circuit voltage (V_{oc}), current at a predetermined voltage (I_V), and the cell current (I_{cell}) and voltage (V_{cell}).

The equipment utilized in this task showed that an automated system for collecting solar cell electrical performance data is extremely conducive to module assembly. A continuation of this data acquisition system for solar cells on an extension to include solar cell modules for large scale automation was performed in connection with Task S and is discussed in detail in that section.

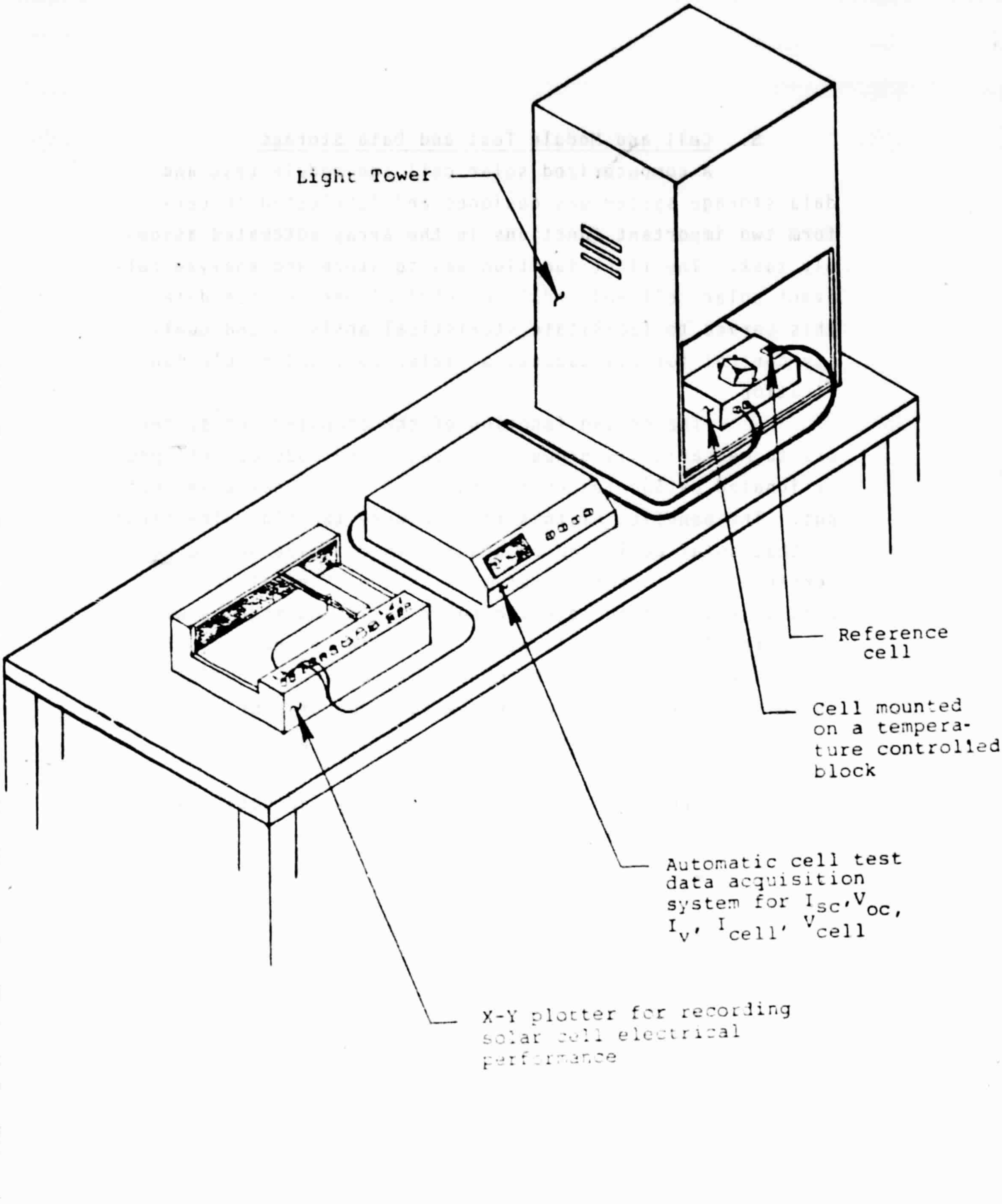


Figure 34. Sketch of Experimental Apparatus for the Automatic Cell Test Data Acquisition System.

S. Cell and Module Test and Data Storage

A computerized solar cell and module test and data storage system was designed and fabricated to perform two important functions in the array automated assembly task. The first function was to store and analyze relevant solar cell and module electrical performance data. This served to facilitate statistical analysis and quality control for all aspects of solar cell and module fabrication.

The second function of the computerized system was to mechanically group solar cells and modules into predesignated categories on the basis of their peak power output. The benefits of this feature were twofold. The first is that solar cells can be grouped to optimize module performance. The second benefit is that mechanical grouping aids in eliminating rejected solar cells and modules without extensive time utilization, as would be the case if this task was performed by manual inspection. The following discussion will focus on the function of storing and analyzing solar cell and module electrical performance data.

The solar cell and module test and data storage system required the following components:

- Pulsed Xenon solar simulator to test at 100 mW/cm^2 and at 28^oC.
- Electrical performance data acquisition system.
- Microprocessor with proper input, output and interface hardware.
- Software program and floppy disk storage.
- Mechanical actuator and conveyor system (not included in this study).

In order to acquire a microprocessor unit compatible with our requirements, literature pertaining to the microprocessing equipment available at that time was obtained. This literature was thoroughly reviewed and the Motorola M6800 system was subsequently selected. The Motorola M6800 microprocessor development system integrates the CRT display/keyboard with the mainframe of the central processing unit and thus requires no special interfacing. All remaining system components were designed and fabricated.

Following the design and fabrication of the microprocessor hardware, the required software was devised. A simplified flowchart representative of the actual computer program is presented in Figure 35. The object of the main program in this flowchart is to group solar cells in accordance with input data supplied by the programmer. The actual grouping operation is performed by three subroutines within the main program. The first subroutine, shown in Figure 35A, measures and stores V_{oc}. The second subroutine shown in Figure 35B measures and stores I_{sc}. The third subroutine shown in Figure 36C, utilizes a numerical analysis technique to group solar cells on the basis of their peak power output.

The criteria utilized in the grouping operation were as follows:

- Current at maximum power point
- Voltage at maximum power point
- Power at maximum power point

In practice, the majority of the solar cells which comprise a module is interconnected in series, so that each series connected solar cell will provide an identical current output. Since cell groups based upon current

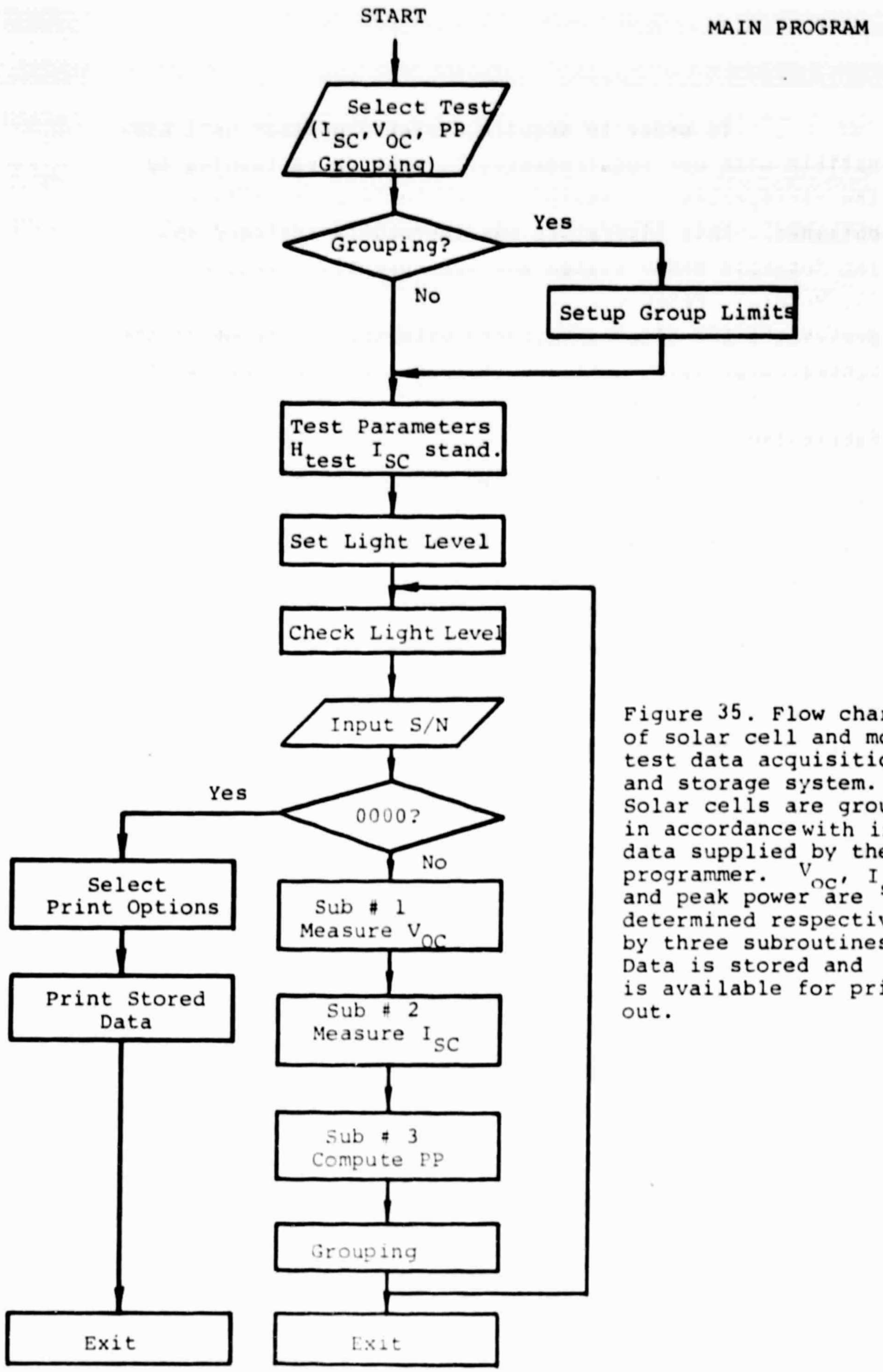


Figure 35. Flow chart of solar cell and module test data acquisition and storage system. Solar cells are grouped in accordance with input data supplied by the programmer. V_{oc}, I_{sc} and peak power are determined respectively by three subroutines. Data is stored and is available for print out.

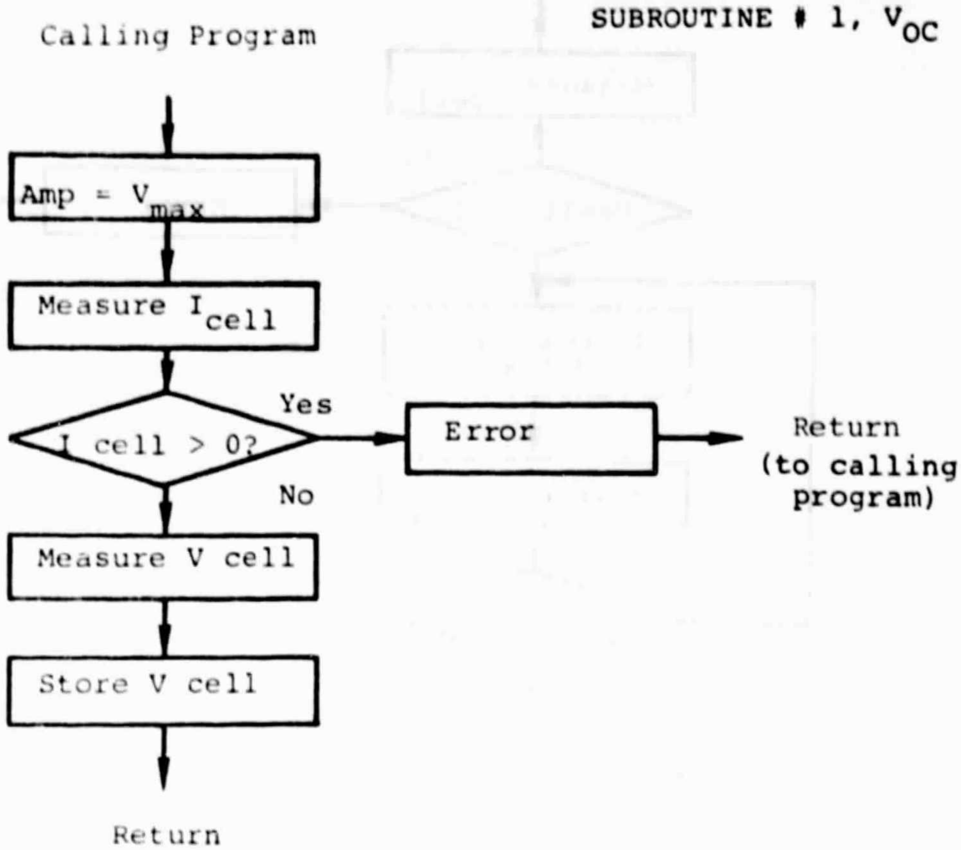


Figure 35A. Flow chart of subroutine number one for measuring open circuit voltage of solar cells or module.

Note: Amp V_{in} is set to a maximum. This efficiency discounts the unit under test from the load so that V_{oc} may be measured. I_{cell} is checked first and if it is greater than zero then an error occurs because V_{OC} is higher than what the equipment can measure.

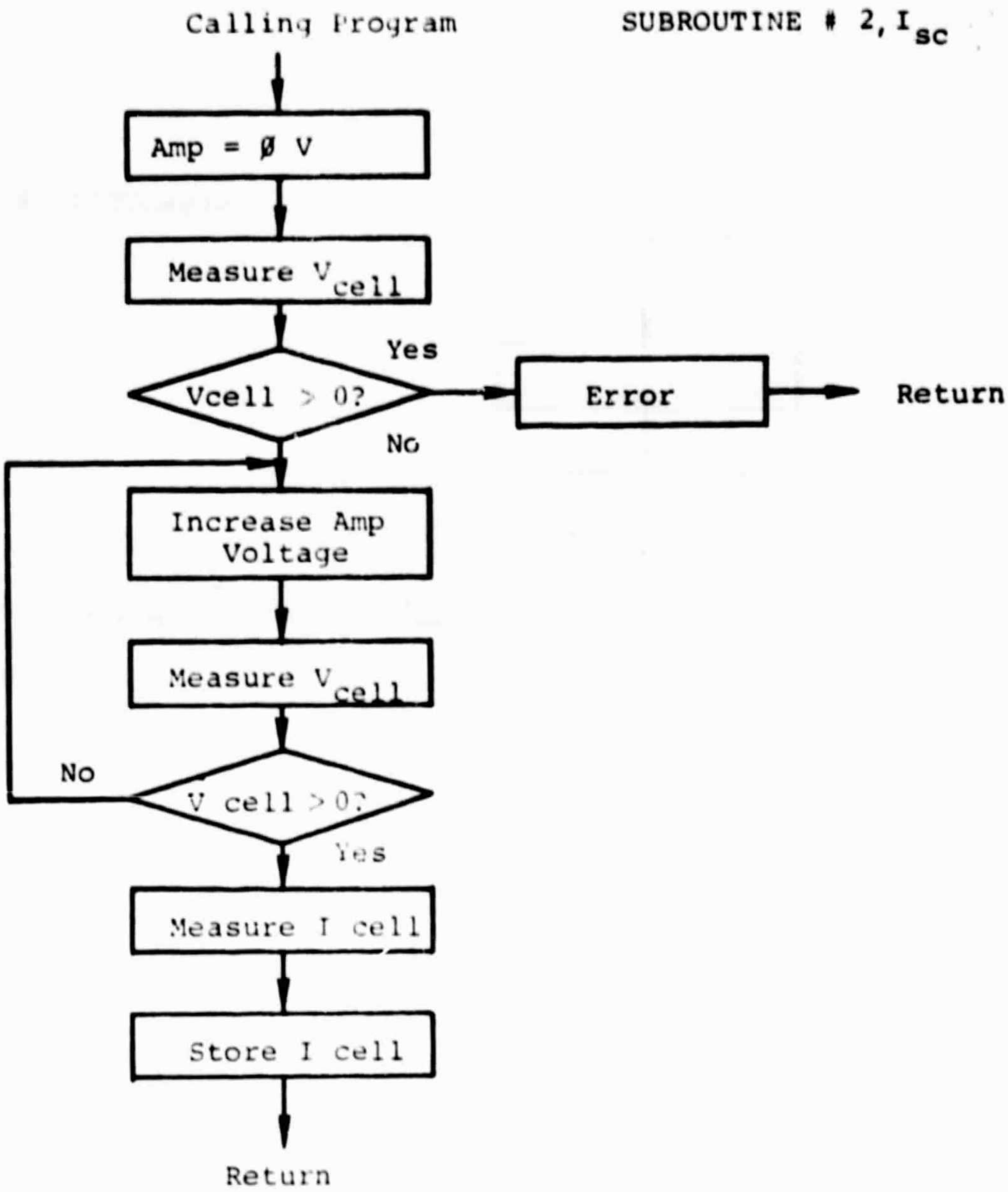


Figure 35 B. Flow chart of subroutine number two to measure short circuit current of solar cell or module.

Note: Amp V_{in} is set to a maximum. This effectively discounts the unit under test from the load so that V_{OC} may be measured. I_{cell} is checked first and if it is greater than zero then an error occurs because V_{OC} is higher than what the equipment can measure.

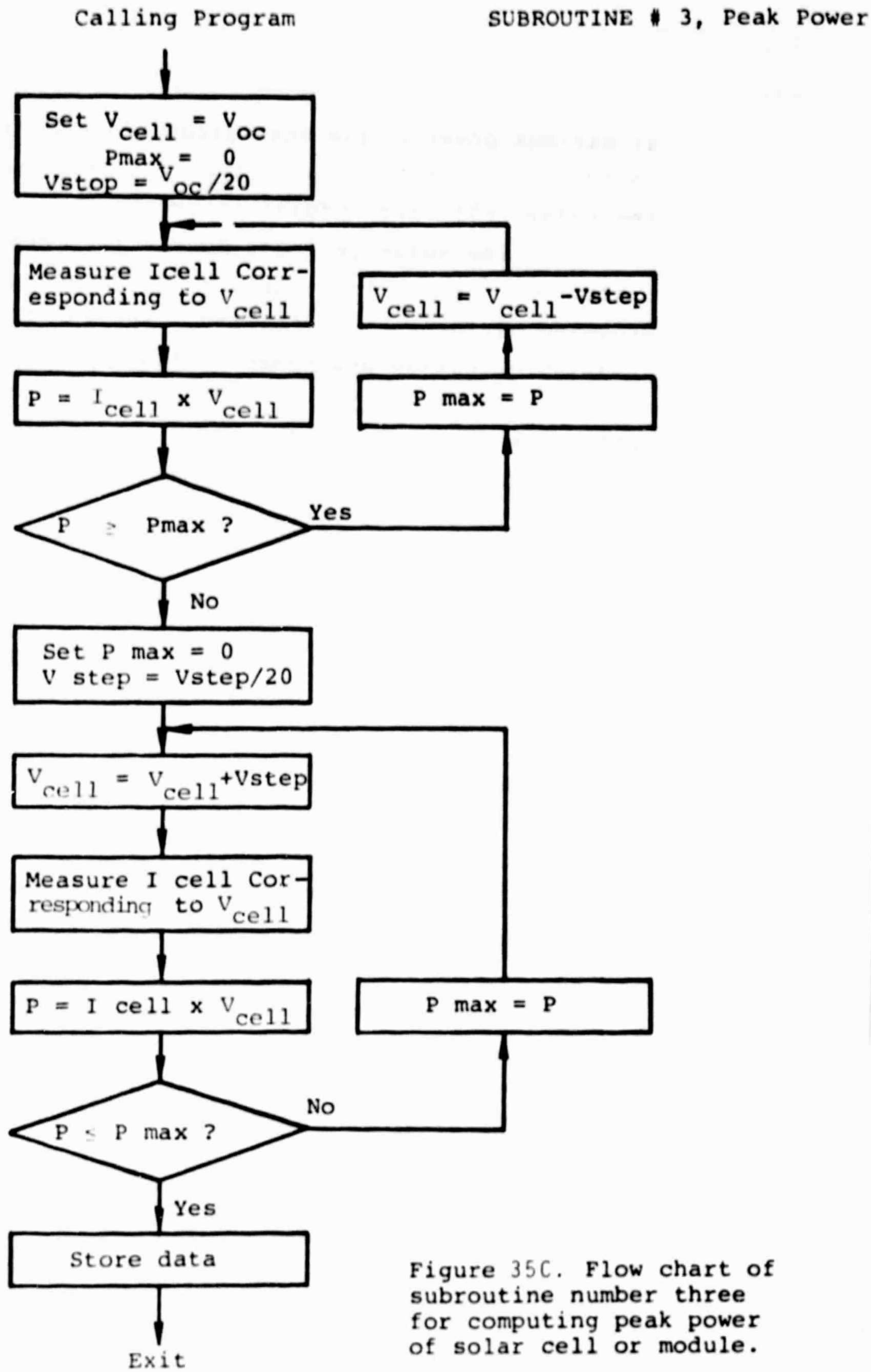


Figure 35C. Flow chart of subroutine number three for computing peak power of solar cell or module.

at maximum power is the most plausible grouping criterion in this case, the microprocessor was programmed to group the solar cells and modules accordingly.

The solar cell and module test and data storage system was tested to establish its data analysis and grouping performance capability. The verification of the grouping operation proceeded in four stages.

The first stage involved the grouping of solar cells with premeasured electrical performance characteristics. Ten solar cells, from three separate groups of 2.15 inch diameter production solar cells, were selected and mixed with two groups of similar rejected solar cells. A total number of fifteen solar cells was selected for test. The solar cells were identified by a four digit serial number. The first digit indicates the premeasured electrical performance group (one indicates the good solar cells and five indicates the rejected solar cells), and the fourth or last digit indicates the cell number used in a particular group. For example, 2003 indicates the second group, third solar cell.

The solar cell data acquisition and storage system was programmed to group the solar cells based on 10 ma current increments from 460 ma to 530 ma at peak power. The current groups were chosen by the programmer and were part of the input data prior to the tests. Up to one hundred groups can be selected. The selected parameters to be measured were: short circuit current, I_{sc}, open circuit voltage, V_{oc}, peak power, and grouping. The tests were performed and the data stored. The results were printed out and are shown in Table 24. A one-to-one correspondence exists between the two grouping methods which is indicative of the success of the computerized grouping operation.

Table 24. Solar Cell Data Acquisition and Storage System Printout. The Solar Cells are Grouped According to Selected Current Increments at Peak Power and at a Light Intensity of 100 mW/cm^2, Xenon.

TEST LIGHT LEVEL (mW/CM^2) 100.0
ABSOLUTE LIGHT LEVEL (mW/CM^2) 111.5

Selected Parameters to be Measured: I_{sc}, V_{oc} Peak Power Grouping

GROUP	MIN. I_p MA	MAX I_p MA
00	0000	0460
01	0460	0470
02	0470	0480
03	0480	0490
04	0490	0500
05	0500	0510
06	0510	0520
07	0520	0530
08	0530	9999

S#	V_{oc} MV	I_{sc} MA	P_p MW	V_p MV	I_p MA	GRP
4002	0532	0568	0180	0427	0422	00
3004	0537	0573	0222	0427	0522	07
3003	0537	0585	0221	0439	0505	05
5002	0537	0576	0201	0446	0451	00
5001	0527	0583	0200	0446	0449	00
2001	0537	0571	0232	0446	052?	07
5003	0515	0549	0128	0400	0322	00
3002	0539	0576	0227	0446	0510	05
2004	0541	0571	0233	0446	0524	07
1001	0544	0573	0239	0458	0522	07
2003	0537	0583	0235	0446	0527	07
3001	0559	0551	0236	0466	0507	05
5004	0505	0524	0097	0332	0295	00
3005	0544	0576	0221	0454	0488	03
1002	0534	0581	0238	0451	0529	07
4002	0532	0558	0180	0427	0422	00
0000						

The second stage checked the system capability to detect a wide range of solar cell current variations. The results of this performance verification test are presented in Table 25 which was generated by shadowing a solar cell to varying degrees. As is apparent from the table, the computerized system is able to detect a wide range in solar cell current variations.

The third stage involved the grouping of modules with premeasured electrical performance characteristics. Three solar cell modules from two different groups were selected. The results of this performance verification test are presented in Table 26, where it can be seen that the data acquisition and storage system grouped the modules into two categories which agreed with the premeasured electrical performance.

The fourth stage proceeded analogously to the second state; however, in this case the system capability to detect a wide range of solar cell module current variations was investigated. The results of this performance verification test are presented in Table 27, which was generated by shadowing one module to varying degrees. As is apparent from the table, the computerized system is able to detect a wide range of solar cell module current variations.

The grouping operation has thus been shown to be highly successful in all respects. The first conclusion which may be drawn from the experimental data is the existence of a one-to-one correspondence between the commonly utilized manual grouping method and the computerized grouping method. It can also be concluded that the computerized solar cell and module test and data storage system are capable of easily detecting a wide range of solar cell and module current variations. An

Table 25. Solar Cell Data Acquisition and Storage System Printout. The System Capability to Detect a Wide Range of Solar Cell Current Variations is Demonstrated by Shadowing a Solar Cell to Varying Degrees, Group Numbers are Arbitrary

TEST LIGHT LEVEL (mW/CM^2) 100.0
ABSOLUTE LIGHT LEVEL (mW/CM^2) 104.4

Selected Parameters to be Measured: I_{sc}, V_{oc} Peak Power Grouping

GROUP	MIN I_p MA	MAX I_p MA
00	0000	0100
01	0100	0200
02	0200	0300
03	0300	0400
04	0400	0500
05	0500	9999

S#	V_{oc} MV	I_{sc} MA	P_p MW	V_p MV	I_p MA	GRP
9999	0524	0375	0095	0295	0324	03
9999	0527	0378	0095	0295	0324	03
9999	0524	0375	0095	0295	0324	03
9999	0524	0378	0095	0295	0324	03
9999	0524	0375	0095	0307	0312	03
1111	0522	0302	0082	0295	0278	02
1111	0522	0302	0082	0295	0278	02
1111	0522	0302	0082	0295	0278	02
1111	0522	0302	0082	0295	0278	02
2222	0500	0136	0042	0358	0119	01
2222	0500	0136	0042	0358	0119	01
2222	0502	0136	0042	0358	0119	01
2222	0502	0136	0042	0358	0119	01
3333	0507	0166	0052	0358	0146	01
3333	0507	0163	0050	0334	0151	01
3333	0507	0163	0050	0334	0151	01
4444	0520	0246	0072	0327	0222	02
4444	0520	0246	0072	0327	0222	02
4444	0520	0246	0072	0327	0222	02
5555	0529	0393	0098	0300	0329	03
5555	0529	0393	0098	0314	0314	03
5555	0529	0393	0098	0300	0329	03
9999	0529	0375	0096	0295	0327	03
9999	0529	0375	0096	0295	0327	03
9999	0529	0375	0096	0307	0314	03
0000						

Table 26. Solar Cell Module Data Acquisition and Storage System Printout. The Modules are Grouped According to Selected Current Increments at Peak Power and a Light Intensity of 100 mW/cm^2, Xenon.

TEST LIGHT LEVEL (mW/CM^2) 100.0
ABSOLUTE LIGHT LEVEL (mW/CM^2) 112.5

Selected Parameters to be Measured: I_{sc}, V_{oc} Peak Power Grouping

GROUP	MIN I_p MA	MAX I_p MA
00	0000	2300
01	2300	2400
02	2400	2500
03	2500	5000
04	5000	9999

S#	V_{oc} MV	I_{sc} MA	P_p MW	V_p MW	I_p MA	GRP
7405	4457	2651	7237	3137	2307	01
7386	3964	2756	6999	2902	2412	02
7407	3952	2683	7498	3100	2419	02
0000						

Table 27. Solar Cell Module Data Acquisition and Storage System Printout. The System Capability to Detect a Wide Range of Module Current Variations is Demonstrated by Shadowing the Module to Varying Degrees.

TEST LIGHT LEVEL (mW/CM^2) 100.0
ABSOLUTE LIGHT LEVEL (mW/CM^2) 102.00

Selected Parameters to be Measured: I_{sc}, V_{oc} Peak Power Grouping

GROUP	MIN I_p MA	MAX I_p MA
00	0000	1500
01	1500	1750
02	1750	2000
03	2000	2250
04	2250	2500
05	2500	9999

S#	V_{oc} MV	I_{sc} MA	P_p MW	V_p MV	I_p MA	GRP
1001	4497	2724	7426	3359	2211	03
1002	4497	2604	7414	3398	2182	03
1003	4492	2492	7314	3410	2145	03
1004	4494	2551	7395	3405	2172	03
1005	4492	2451	7427	3393	2189	03
1006	4489	2517	7419	3374	2199	03
1007	4497	2973	8955	3359	2666	05
1008	4492	2770	8467	3417	2478	04
1009	4487	2702	7885	3386	2329	04
1010	4450	1833	4398	3420	1286	00
0000						

assessment of the far-reaching potential of the computerized solar cell and module test and data storage system has lead to the expectation that it will immensely simplify the performance of statistical analysis and quality assurance in all areas of solar cell and module fabrication. Therefore, it is recommended for use when high production levels are being performed.

T. Microwave Study

Initially, a prototype instrument was built to conform to the design criteria determined during the first four months of the contract. A block diagram of the unit is shown in Figure 36.

The power source for the instrument consisted of a 0-1 KW Cober variable power generator with a fixed 2.45 GHz frequency output. Although the pulse width and repitition rate are adjustable, the lack of energy coupling to the samples caused the need for operation in the CW mode.

Time exposure was selectable with either a digital timer control or manual mode operation. Power control was selectable from either manual adjustment or automated by use of an IRCON controller. This system measures the IR radiation of the sample and feeds this to an automatic control unit which varies primary power on the generator. Calibration of the camera is done against a diffusion furnace whose temperature has been accurately measured with a Pt-Pt/Rh thermocouple.

Hewlett-Packard Microwave/RF power meters were used to measure both incident and reflected power. The difference between the readings indicated the power absorbed within the cavity.

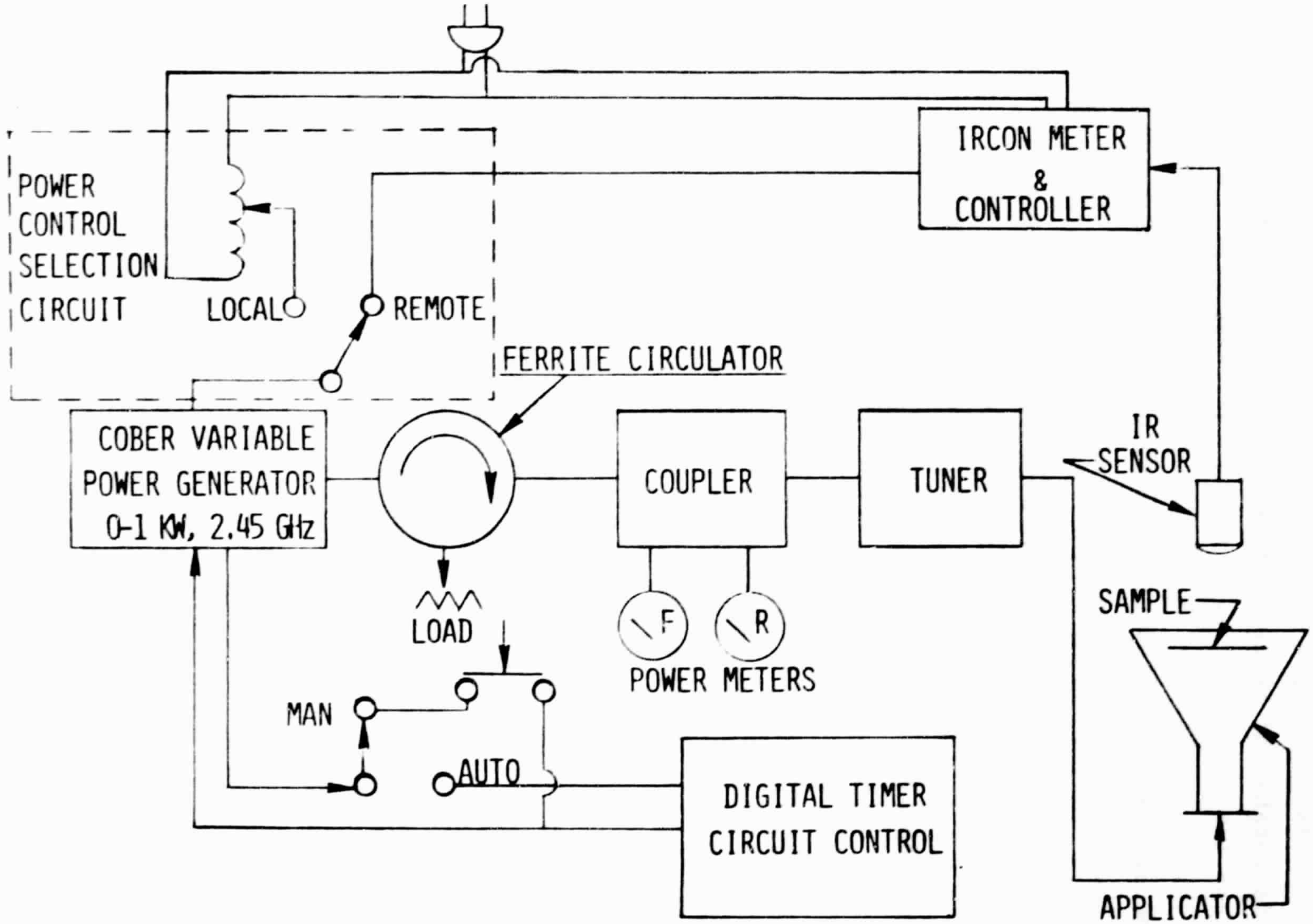


Figure 36. Block Diagram of Prototype Microwave Apparatus.

The microwave cavity is 24 cm x 12 cm and therefore is capable of processing two 10 cm x 10 cm wafers at the same time. Initial experiments indicated that the horn cavity did not perform to the same uniformity as predicted by the analytical model. Two of the reasons being that the coupling efficiency was found to vary as the temperature varied and the edges and center seemed to be heating up faster than the balance of the wafer. This latter phenomenon was attributed to modification of the E-field due to the silicon presence. Excellent performance was obtained on 2 cm x 2 cm silicon, however.

Although the wafers could be heated to $800^{o}C$ in less than five seconds, the variation in uniformity at high temperatures directed that experimental efforts be carried out in two distinct categories: low temperature applications and high temperature applications. The separation point between the two was taken to be $600^{o}C$.

Low temperature applications are in the fields of metal sintering and aluminum back surface field formation, while high temperature applications are in metal paste firing and, potentially, in diffusion.

In low temperature experimentation, metal sintering of the contacts was attempted for nickel metallization. Electroless nickel was deposited from a basic bath using a printed resist as a mask. The contact pull strengths before and after sintering were used as a confirmation of the sintering effect. There was a high uniformity observed when the metal was sintered at $450^{o}C$ for 30 seconds and there was no observable degradation in the function characteristic, indicating a controlled penetration depth. The sintering was done in a nitrogen blanket with 250 watts of microwave power.

In a further low temperature experiment, a printed aluminum paste was placed on the backs of wafers processed as indicated in Figure 37. The V_{oc} measurements, in the 585-600 mv range, indicated the ineffectiveness of the field formed. The drive-in was performed at 500^{o}C for four minutes. Figures 38 and 39 show the curve brackets measured before and after edge grinding. They indicate an ohmic contact was formed and sample number four was a result of edge shunting and not lack of ohmic contact.

To evaluate high temperature sintering, wafers were screened with a silver paste in a pattern normally used for front metallization. These were then sintered at 700-725^{o}C for 45 seconds. A similar contact pull strength increase was found, but the I-V curves indicated that the junction has been penetrated. The wafers were segmented and remeasured. Some segments showed the same junction shorting while others did not, indicating non-uniformity of heating.

The experiments summarized above indicated the basic soundness of the investigation of microwave energy for application within the field of solar cell fabrication. Conversely they also indicated the need for a re-design of the applicator and associated equipment. These efforts were beyond the scope of this contract. As a result, the conclusions reached at this time are:

1. The process has potential for application to solar cell fabrication in the future.
2. At present, limitations exist in the equipment that must be overcome before direct application of this technology can occur.
3. The efforts required are at the research level and the primary value of the work done on this contract has been to point out this requirement.

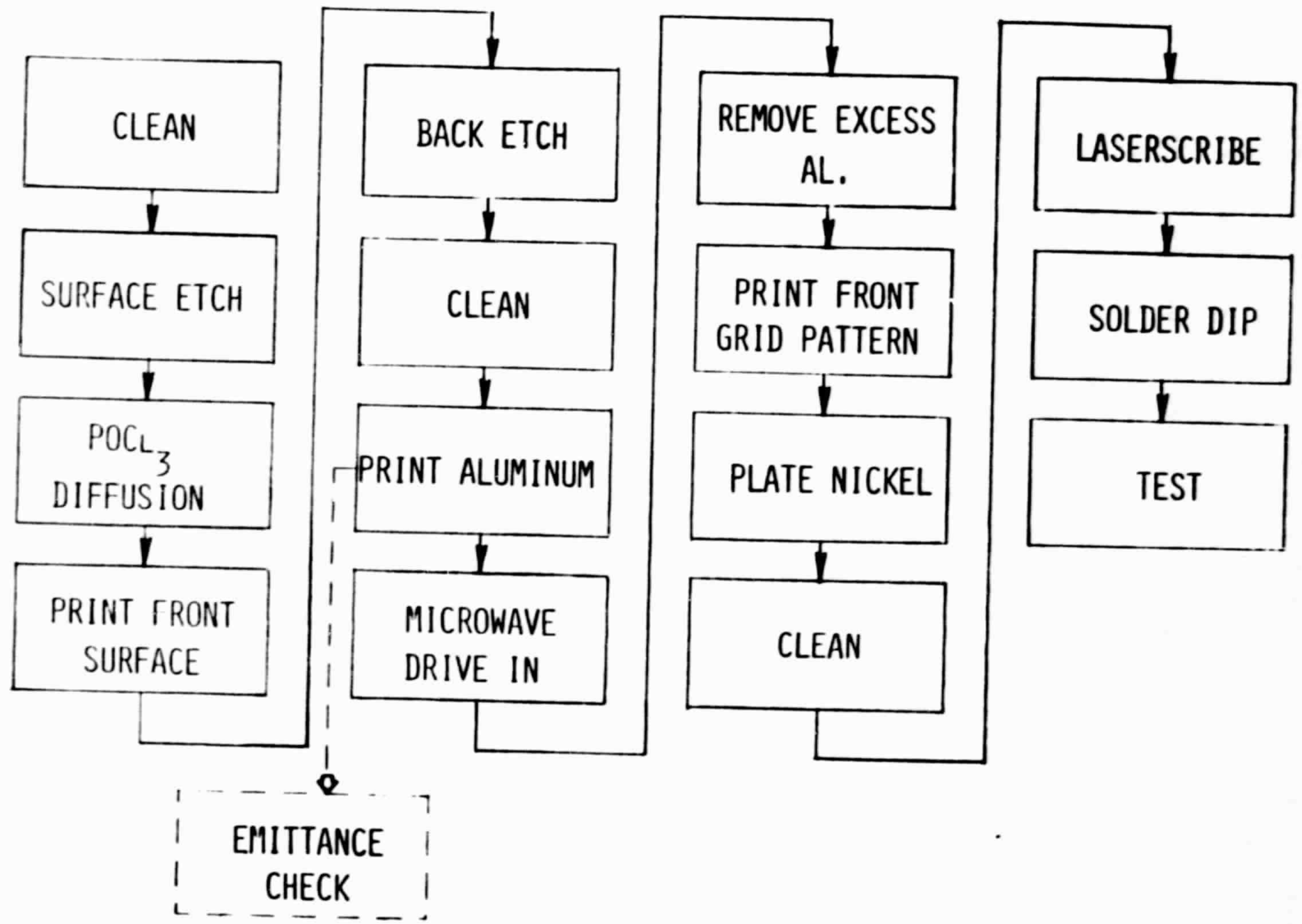


Figure 37. Microwave Process Flow Chart.

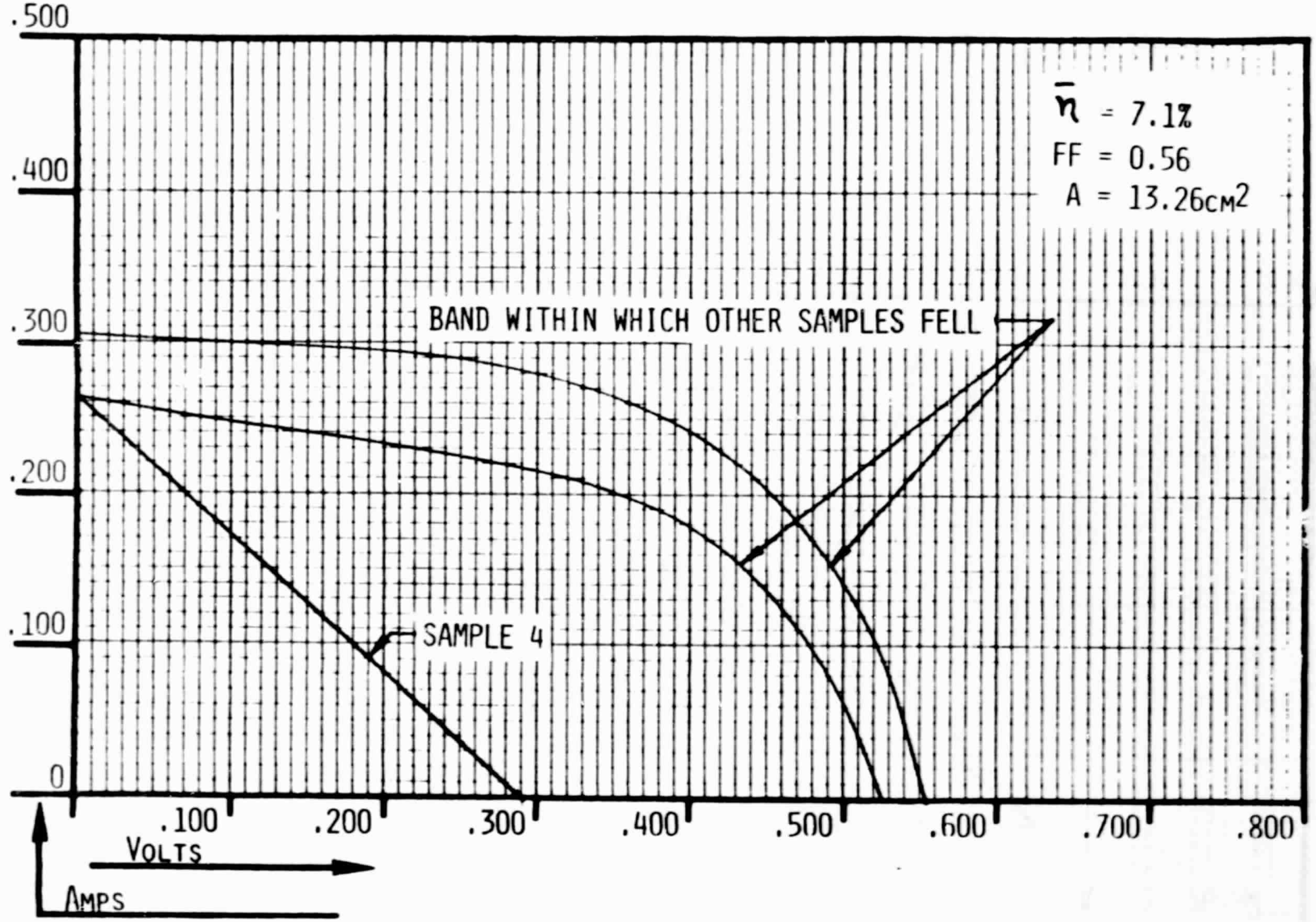


Figure 38. Printed Al, Microwave Drive 490^{o}C-530^{o}C, Four Minutes, Not Edge Ground.

ORIGINAL PAGE IS OF POOR QUALITY

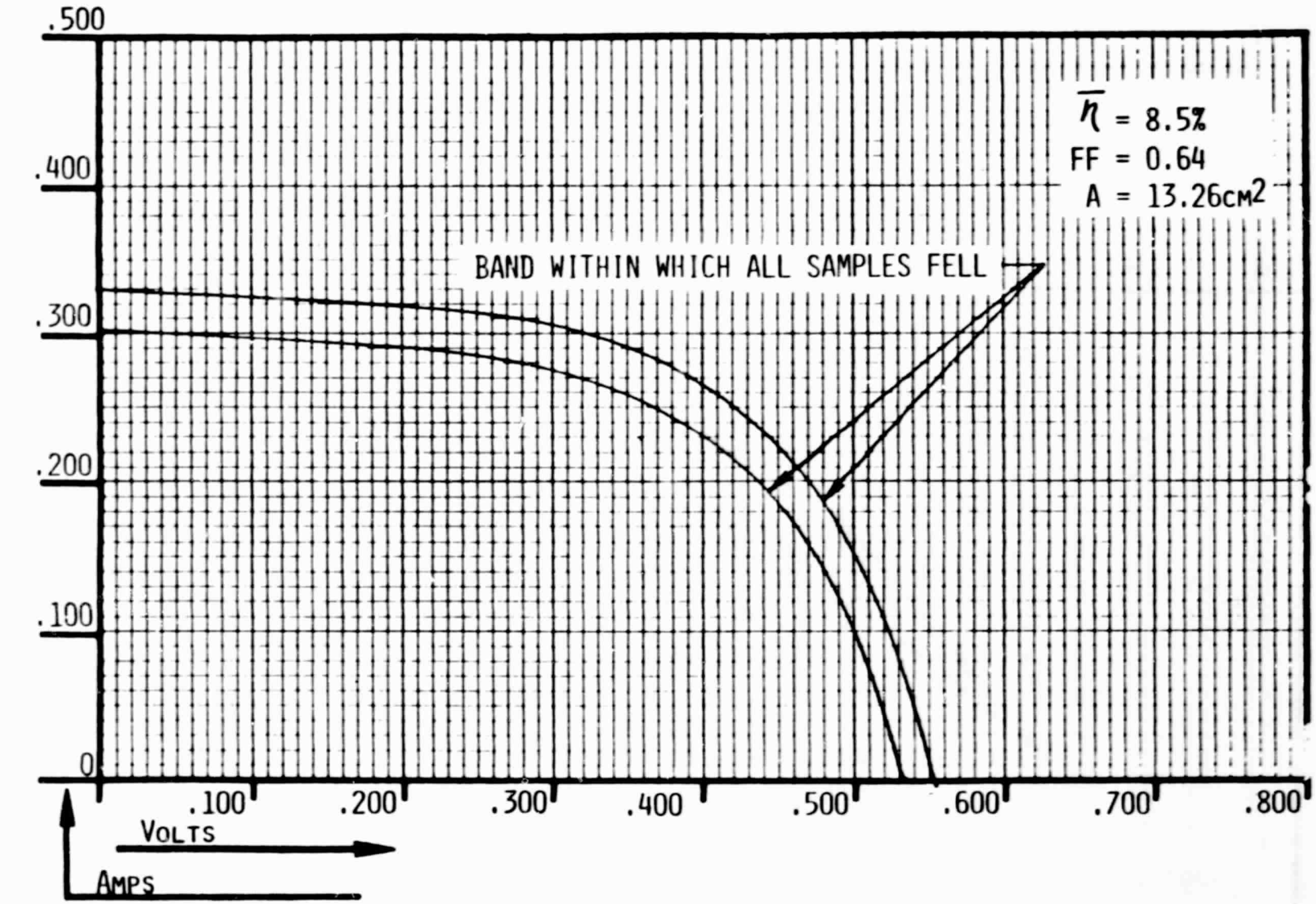


Figure 39. Printed Al, Microwave Drive 490°C-530°C, Four Minutes, Edge Ground.

IV. SAMICS ANALYSES

All Low-Cost Solar Array (LSA) projects require a thorough cost analysis to establish their potential for meeting certain specific price goals. Since process cost estimation methods differ from one company to the next, Solar Array Manufacturing Industry Costing Standards (SAMICS) are recommended. The SAMICS method allows one to make a relative comparison between potential prices attributable to competing processes and to obtain the best possible process price estimate.

A SAMICS cost analysis was performed for each valid process step studied for Phase 2 of the Array Automated Assembly Task. Initially, a simplified preliminary cost analysis was implemented for each process step, in order to elicit a relative comparison between competing processes. The processes which displayed the lowest overall cost were selected for use in a model automated production line. The more costly competing processes were rejected.

Since large volume production at high throughput rates is essential for meeting the 1986 LSA goals, the automation potential of each of the selected processes was evaluated. If state-of-the-art technology was available to produce automated versions of the current process equipment, the automated equipment was utilized in the model company. However, in those cases for which current technology was deemed inadequate to produce automated process equipment, the existing unmodified version was utilized in the model company. In several cases, a number of important intermediate process steps included within a complete process received minor emphasis in this program, as they are standard process steps presently in use at Photowatt International, Inc.

Several SAMICS procedures were updated during the course of this program. Therefore, all SAMICS results presented in this study reflect the latest SAMICS revisions.

All hypothetical industries utilized in SAMICS are the 1986 standards as defined by the Interim Price Estimation Guidelines, (IPEG) in Reference (3). Input data preparation and process cost computations were performed in accordance with References (4), (5), (6) and (7). All expense items were evaluated on the basis of the cost account catalog in reference (8). If an expense item is not included in the cost account catalog (Reference 8), it may be located in the temporary catalog (Appendix IV). Specific input data utilized in the process cost estimations are presented in Appendix II and Appendix III.

A. Description of the Industry

The structure of the industry is assumed to be the 1986 standard industry as defined in Reference (3). The model industry is composed of a sequence of companies, each of which is an independent financial entity. A total of five successive companies constitutes the model industry. This study focussed on only two of these companies; the cell manufacturing company and the module manufacturing company. It was assumed that all remaining companies of the model industry operate under the current price goals defined in Reference (3). The two companies under consideration in this study will hereby be designated as CELLCO and MODULCO, which manufacture photovoltaic cells and modules, respectively.

The basis assumptions utilized in the standard industry are listed below:

(1) CELLCO and MODULCO are vertically integrated companies, which share 40 percent of their corresponding markets. CELLCO will purchase wafers from WAFERCO at the price of 31 cents per peak watt in 1980 cents as set forth in Reference (3). MODULCO will purchase 100% of its solar cells from CELLCO.

(2) A double burden was not charged for silicon wafers or cells since the companies are assumed to be vertically integrated as defined in Reference (6).

(3) CELLCO and MODULCO require 4.7 person-shifts per day (24 hrs), for 345 operating days. All remaining modifications specified in Reference (6) were utilized in the analysis.

(4) CELLCO and MODULCO maintain a production yield of 96.3% and 95.1%, respectively.

(5) The module cost is based upon both its mechanical design and electrical performance capability. The detailed product description can be summarized as follows:

Module Size: 2' x 4'

Number of Cells: 119 equivalent modified hexagonal cells (102 full cells and 34 half cells)

Cell Efficiency: 14.7% after encapsulation

Packing Factor: 87%

Usable Silicon Per Wafer: 81%

Cell Size: 90 mm point-to-point diameter modified hexagonal solar cell with 51.32 cm^2 cm^2 area.

Module Output: 90 watts (0.76 watts/cell) at 100 mW/cm^2 insolation.

In view of the above specifications, the anticipated annual production quantity for the two companies is as follows:

CELLCO: 278 million solar cells per year or 210.3 MW per year.

MODULCO: 2.222 million modules per year or 200 MW per year.

These output rates are utilized in the SAMICS analysis. The industry definition is presented in Format C, in Appendix I.

B. CELLCO FIRM

B1. Company Description

The CELLCO firm is a model company in the 1986 standard industry which produces solar cells from silicon wafers. The annual production quantity for this company is 278 million solar cells per year which is equivalent to 210 MW.

The selection of a solar cell fabrication process sequence for CELLCO was based on the results of the SAMICS cost analysis performed for all process steps investigated in this array automated assembly program. A fully automated production line consisting of nine solar cell processes was selected for CELLCO. A conceptual layout of the model plant is shown in Figure 40.

The Photowatt/Sensor Technology CELLCO plant was designed to produce approximately 40 MW per year, or about 7200 wafers per hour. Five production lines will therefore be required to produce 200 MW per year, which is 40 percent of the total market.

A brief description of each of the nine processes selected for use in the CELLCO model plant is given below:

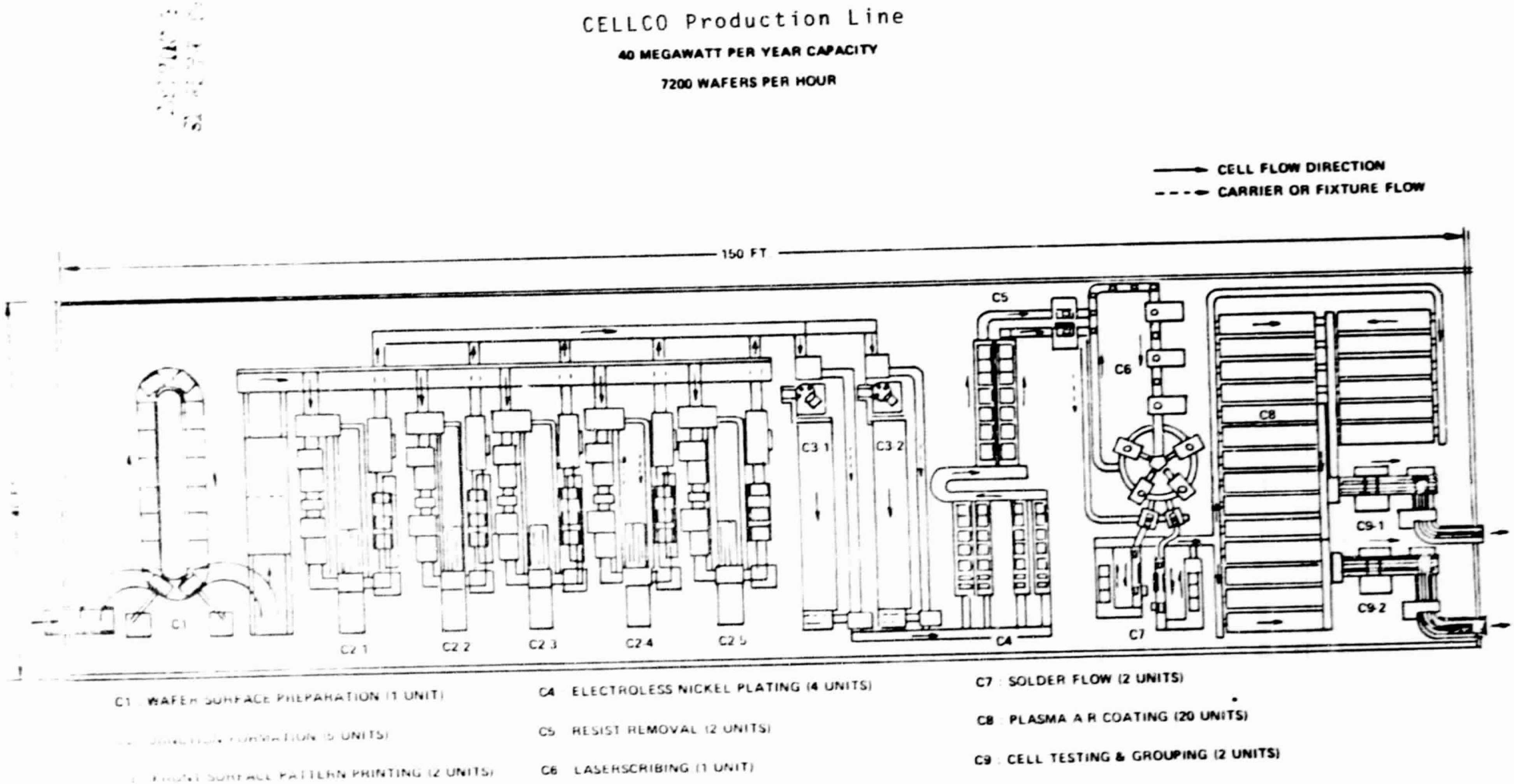


Figure 40. Photowatt/Sensor Technology CELLCO Production Line.

(C-1) Wafer Surface Preparation (WFSURPR)

This process step consists of wafer surface cleaning, wafer surface texturizing, and final cleaning and drying.

(C-2) Junction Formation (JUNCF)

The junction formation process sequence includes: spray-on n^+ dopant onto the front surface with a subsequent IR bake, spray-on p^+ dopant onto the back surface with a subsequent IR bake, dopant drive-in of both surfaces, followed by excess dopant removal.

(C-3) Front Surface Pattern Printing (FSPP)

An initial process step prior to metallization is thick film resist printing by means of a negative mask. Metallization pattern printing of the front surface is followed by a standard drying process.

(C-4) Electroless Nickel Plating (ELNIPL)

This is an active metallization process. Nickel is plated onto the front surface gridline pattern, as well as the entire back surface. A cleaning step after plating completes this process step.

(C-5) Resist Removal (RESREM)

This process consists of wet chemical resist removal followed by a standard wafer cleaning and drying procedure.

(C-6) Laserscribing (HEXLS)

An automatic lasercribing system for large volume production was developed and utilized in this program. The laserscribe performs the scribing of solar cells.

(C-7) Solder Flow (SDFLW)

The front surface grid pattern and back surface are solder coated in this process. The complete solder flow process consists of preheating, flux application, solder dipping, and flux removal.

(C-8) Antireflective Coating (ARCT)

The solar cell antireflective coating is applied by silicon nitride plasma deposition.

(C-9) Cell Testing and Grouping (CELLTEST)

Solar cells are automatically tested, analyzed and grouped according to electrical performance.

B2. Process Description

B2.1. Wafer Surface Preparation

B2.1.1. Design for High Volume Production

A wafer surface texturizing study was performed in this program with the use of Sensor Technology's existing texturizing equipment. On the basis of the resulting process cost computation, the conceptual design for the large volume production line shown in Figure 41 was devised.

This fully automated system consists of twelve equally spaced identical tanks. Each tank is capable of holding twelve wafer carriers situated on a platform lift. Since each wafer carrier can hold up to 50 wafers, 600 wafers constitute one batch.

Each batch remains in its corresponding process tank for five minutes and then transfers to the next station during a one minute time period. The transfer mechanism utilized in this process step consists of a lifter at each station and an over-hung track conveyor. The conveyor transfers each platform to its corresponding station, and lifters move the platforms up and down within the tank. The function of each tank is specified in Figure 41.

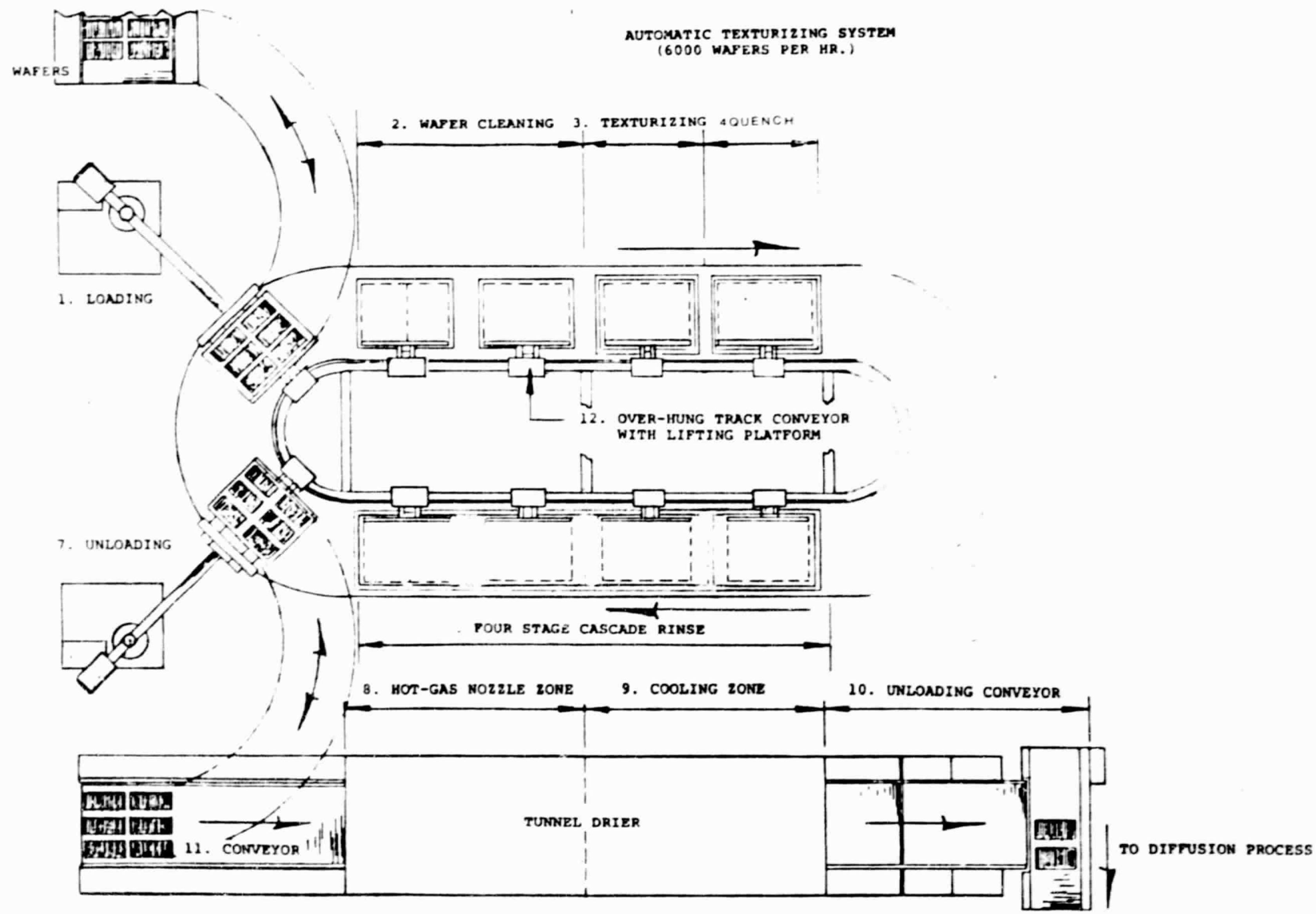


Figure 41. Automatic Texturizing System, 6000 Wafers per hour.

B2.1.2. Supporting Data for Format A

The process cost estimation for the wafer surface preparation task entailed the following cost elements.

B2.1.2.1. Equipment Costs

TEXTURIZING SYSTEM	
Frame and tanks	$24,000
Supporting tanks	4,000
Ultrasonic and other accessories	12,000
Moving hoist lifter and conveyor	14,000
Mail drive system	6,000
Control system including gauges	10,000
Engineering and design	10,000
Burden (50%)	40,000
DRIER SYSTEM	
Tunnel chambers and conveyor	$10,000
Nozzle, heater and fan control	11,000
Burden (50%)	10,000
LOADER AND UNLOADER SYSTEM	
Two loaders and one conveyor unloader	$20,000
TOTAL SYSTEM COST	$171,000

B2.1.2.2. Floor Space

The layout for the prototype system depicted in Figure 41 indicates a floor space requirement of 448.82 ft.^{2}

B2.1.2.3. Labor

One operator is sufficient to run the fully automated texturizing system. It was assumed that the remaining labor requirements include 0.1 maintenance man, 0.1 Q.C. inspector, and 0.02 production planer.

B2.1.2.4. Utilities and Commodities

It was assumed that chemical consumption rates are directly proportional to the production throughput rate. Consequently, each chemical consumption rate utilized in the high volume texturizing system is related to its corresponding chemical consumption rate in the actual test model by the throughput ratio between the two systems.

The electrical power consumption rate of 0.289 KW-hr/minute was estimated on the basis of a thorough design analysis performed on the texturizing system shown in Figure 41.

B2.2 Junction Formation (JUNF)

B2.2.1. Design for High Volume Production

The spray-on dopant junction formation system utilized in the conceptual high volume production line is a modified version of Advanced Concepts Model SC100 (Ref. 6, Task 15) with a throughput rate of 1200 wafers/hr. The junction formation process is composed of three distinct process steps. The first process step is spray-on of n^+ and p^+ polymer dopants onto the front and back wafer surfaces, respectively, followed by dopant bake-in. The second process step is dopant drive-in. A readily obtainable, conventional rectangular diffusion furnace with a throughput rate of 1200 wafers/hr. is used in this process step. The only additional required equipment utilized for dopant drive-in is an automatic loading device for loading wafers into boats, and then boats into the diffusion furnace. The third process step is excess dopant removal which involves dipping a wafer carrier emerging from the dopant drive-in process, into a hydrofluoric acid etching tank. A three-stage cascade rinse and drying procedure completes this process step.

The schematic diagram for the conceptual high volume junction formation system is presented in Figure 42. The systematic operation of the spray-on-dopant junction formation system can be described as follows: (1) wafers are loaded onto conveyor, (2) n^+ polymer dopant is sprayed onto the front wafer surface, (3) wafers are transported through I-R oven, (4) wafers are flipped over, and the same procedure is repeated with P^+ polymer dopant sprayed on the back wafer surface.

B2.2.2. Supporting Data for Format A

The process cost estimation for the spray-on dopant junction formation task entailed the following cost elements.

B2.2.2.1. Equipment

Equipment cost estimations utilized in the SAMICS cost analysis of the spray-on junction formation process are presented below.

SPRAY-ON SYSTEM	
2 spray-on units	$40,000
Loader and unloader	5,000
Flip over mechanism	2,500
Pallet return conveyor	500
Pallets	200
Total	$48,000

DRIVE-IN SYSTEM	
15 KW, 1500°C, 5" x 7" x 30" Brute diffusion furnace	$20,000
Loader and unloader	5,000
Quartz boats and tubes	500
Total	$25,500

EXCESS DOPANT REMOVAL	
HF tank and rinse tank	$ 4,500
Material handling system	2,000
Loader	2,000
Drier	5,000
Total	$13,500

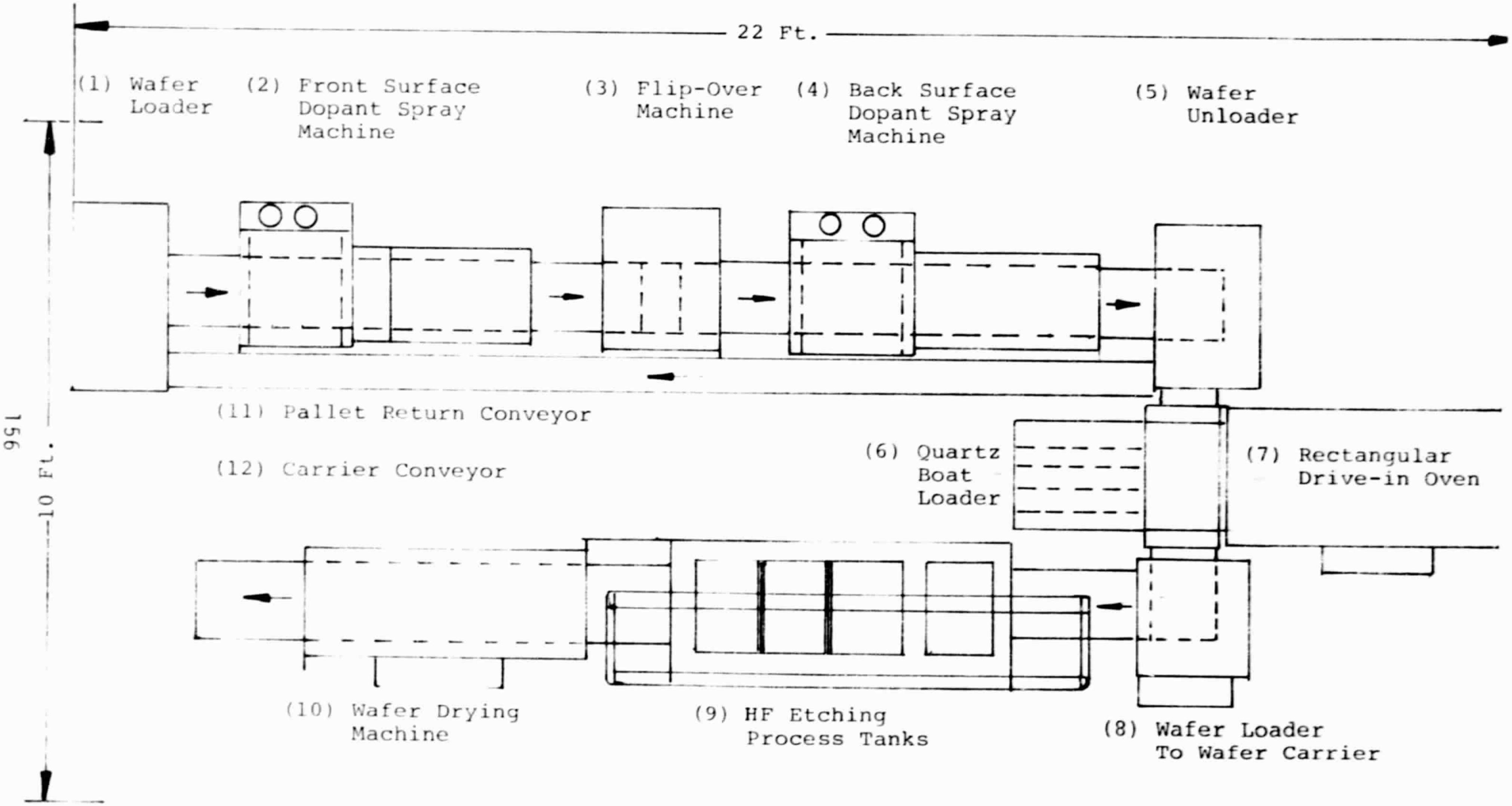


Figure 42. Conceptual Design of Spray-on Dopant Junction Formation System (1200 wafers/hr. capacity).

B2.2.2.2. Floor Space and Labor

The floor space requirement of 220 sq. ft. was estimated on the basis of the schematic diagram presented in Figure 42. One operator is sufficient to handle four spray-on dopant junction formation systems. The remaining labor requirements are identical to the wafer surface preparation task.

B2.2.2.3. Utilities and Commodities

All utility and commodity requirements presented in Format A have been obtained directly from experiments.

The input data utilized for this process cost computation may be located in the appropriate Format A of Appendix II.

B2.3. Front Surface Pattern Printing (FSPP)

B2.3.1. Design for High Volume Production

Front surface pattern printing is the third process performed in the CELLCO firm. This process received detailed analysis in Task 6 of Phase 2 of the Array Automated Assembly Program (Ref. 9). The conceptual design for the high volume front surface pattern printing system is depicted in Figure 43. The complete system is composed of a printer and an I.R. drier tunnel. The printing unit is a modified version of the Fursland Model 33, and has an expected throughput rate of 3000 wafers/hr. The I.R. drier tunnel is strictly a conceptual design.

The wafers emerging from the junction formation process station are transported by a pick-up arm device to the printer. The printer prints the front surface grid pattern design, and then unloads the printed wafers onto a transfer conveyor. The transfer conveyor is equipped with a hot gas blower for preliminary ink drying, and serves to facilitate easy wafer handling between the wafer loader and the drier tunnel.

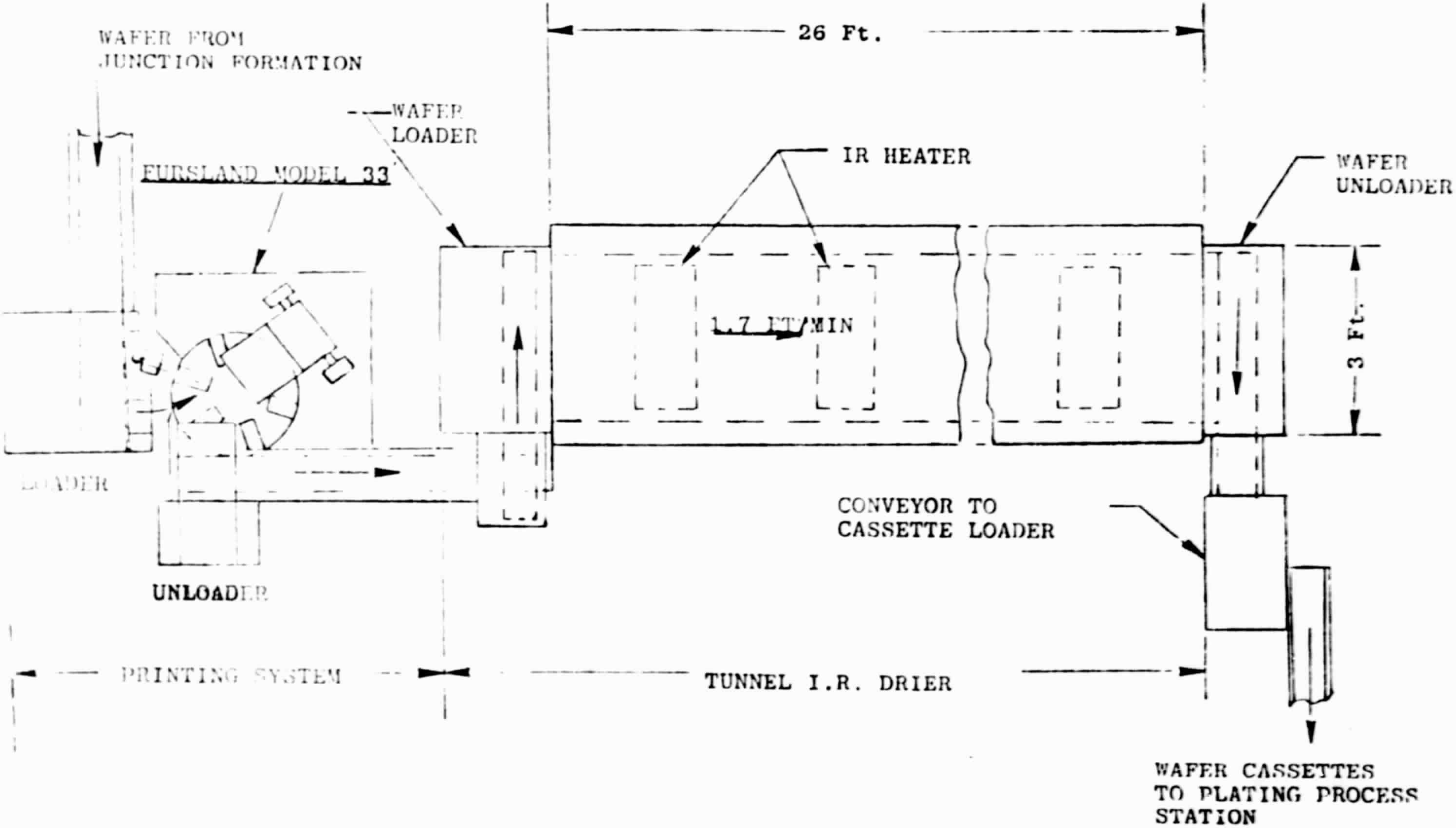


Figure 43. Schematic Layout of Automatic Wafer Printing System (3000 wafers/hr.)

B2.3.2. Supporting Data for Format A

The process cost computation for the front surface pattern printing task entailed the following cost elements.

B2.3.2.1. Equipment Costs

PRINTER

Main machine		$14,000
Loader and unloader		6,000
	Total	$20,000

TUNNEL DRIER

Tunnel chamber and conveyor		$10,000
Fans and main driers		5,000
Heater and control		5,000
	Total	$20,000

B2.3.2.2. Floor Space

The floor space estimation of 360 sq. ft. was obtained directly from the layout drawing.

B2.3.2.3. Labor

One operator is sufficient to operate four complete printing systems. All remaining personnel are assumed to be identical to the wafer surface preparation task.

B2.3.2.4. Materials

The direct materials needed for this operation are printing ink and thinner. The consumption rates of these materials and their unit prices in terms of 1978 dollars are:

Ink: $4.0. \times 10^{-5}$ gal/wafer - $36.16 gal.

Thinner: 8.67×10^{-6} gal/wafer - $45.20 gal.

B2.3.2.5. Utilities

The electrical power requirement for each individual unit is as follows:

Printer	0.315 KW
Fan motors	0.5 hp x 2 = 1 hp
Loader and unloader	0.5 hp x 2 = 1 hp
Main drive	2 hp
I.R. heaters	3 KW x 5 = 15 KW
Total	18.3 KW

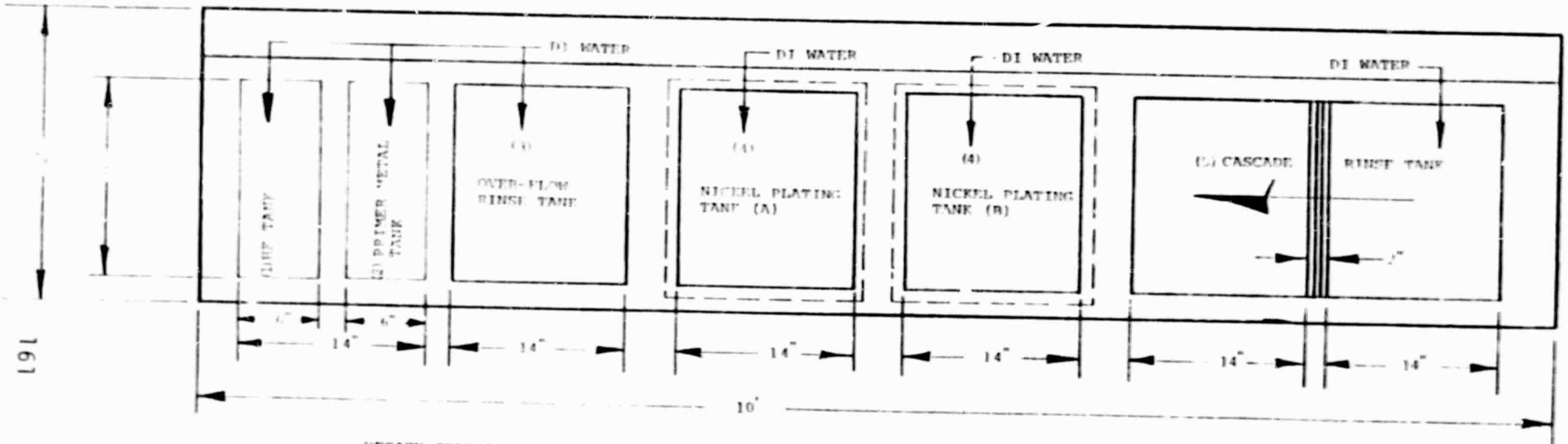
The input data utilized for this process cost computation may be located in the appropriate Format A of Appendix II.

B2.4 Electroless Nickel Plating (ENIPL)

B2.4.1 Design for High Volume Production

The electroless nickel plating study was performed in Task 9 of Phase 2 of the Array Automated Assembly Program (Ref. 9). The schematic diagram of the complete system is shown in Figure 44.

Initial operation of this process begins when the wafers are placed into a hydrofluoric acid etchant tank for 30 seconds and then moved to the gold solution primer metal bath for 30 seconds. Next, the wafers are transferred by an automatic lifter to the overflow rinse tank. After repetition of three cycles of this process, a total of six wafer carriers is collected at the overflow rinse tank. These six carriers are then placed into a carrier basket which automatically transfers to the electroless nickel plating tanks where the wafers remain for five minutes in each tank. The wafers are then automatically transferred to a two-stage cascade rinse system where they reside for ten minutes (five minutes in each tank).



DESIGN SPECIFICATIONS

(A) DEPTH OF TANK = 10" + (3" EXHAUST OUTLET).

(B) MATERIAL: POLYPROPLENE & CORNING GLASS.

(C) THE DRAIN HOLES OF ALL TANKS ARE CONNECTED TO THE SEWER EXCEPT TANK 2 WHICH IS CONNECTED TO RESERVOIR TANK. (RESERVOIR TANK=14"x 16" x 12").

(D) EXHAUST OUTLETS ARE NEEDED FOR TANKS 1,2 & 4, USE AIR KNIFE OR AIR CURTAIN IF POSSIBLE.

(E) DI WATER LINE SHOULD BE INSTALLED AS SPECIFIED.

(F) TANK 4 REQUIRES INDIRECT DUEL WALL HEATING SYSTEM WHICH CAN HEAT 10 GALLONS OF WATER UP TO 85 C WITHIN 20 MINUTES AND MAINTAIN TEMPERATURES AT 85 C ± 5 .

(G) BOTH RINSE TANKS 3&5 REQUIRE FLOW METERS AND A CONTROL VALVE FOR WATER FLOW.

Figure 44. Schematic Layout of Nickel Plating System (1800 wafers/hr. capacity).

The throughput rate for the electroless nickel plating system is 1800 wafers/hr. The machine "up" time fraction is 0.875 by assuming one hour per shift of downtime.

B2.4.2. <u>Supporting Data for Format A</u>

The process cost computation for the electroless nickel plating task entailed the following cost elements.

B2.4.2.1. <u>Equipment Cost</u>

All plating equipment was designed and fabricated at Sensor Technology, Inc. The actual cost of this plating system was $8,232.32. An additional $10,000 must be added to this figure to include the fully automatic material handling system.

B2.4.2.2. <u>Floor Space</u>

Upon taking into consideration operator working space, the floor space requirement is 72 sq. ft.

B2.4.2.3. <u>Labor</u>

One operator can handle four automated systems at full capacity. The remaining labor requirements are identical to the wafer surface preparation task.

B2.4.2.4. <u>Utilities and Commodities</u>

Direct measurements from experimental test runs yielded the following material consumption rates.

- 49% hydrofluoric acid: 0.5 cc/wafer = 0.039 lbs/min. (sp. gr. of sol. = 1.18)
- Gold plating solution (premixed commercial item): 0.5 cc/wafer - 15 cc/min.
- Nickel plating solution (premixed commercial item): 5 cc/wafer = 150 cc/min.
- Nitrogen gas: 10 liters/min. for each tank. Total: 20 liters/min. = 0.706 cu. ft./min.

- D.I. water: 1.5 gal/min. for each rinse tank. Total: 3 gal/min. = 0.401 cu. ft./min.
- Electric power: 3.12 KW heater unit per tank.

  This is used for 30 minutes every three hours. Therefore, the power usage factor becomes 0.1667. Power consumption per minute is 8.66 watts.

The input data used for this process cost computation may be located in the appropriate Format A of Appendix II.

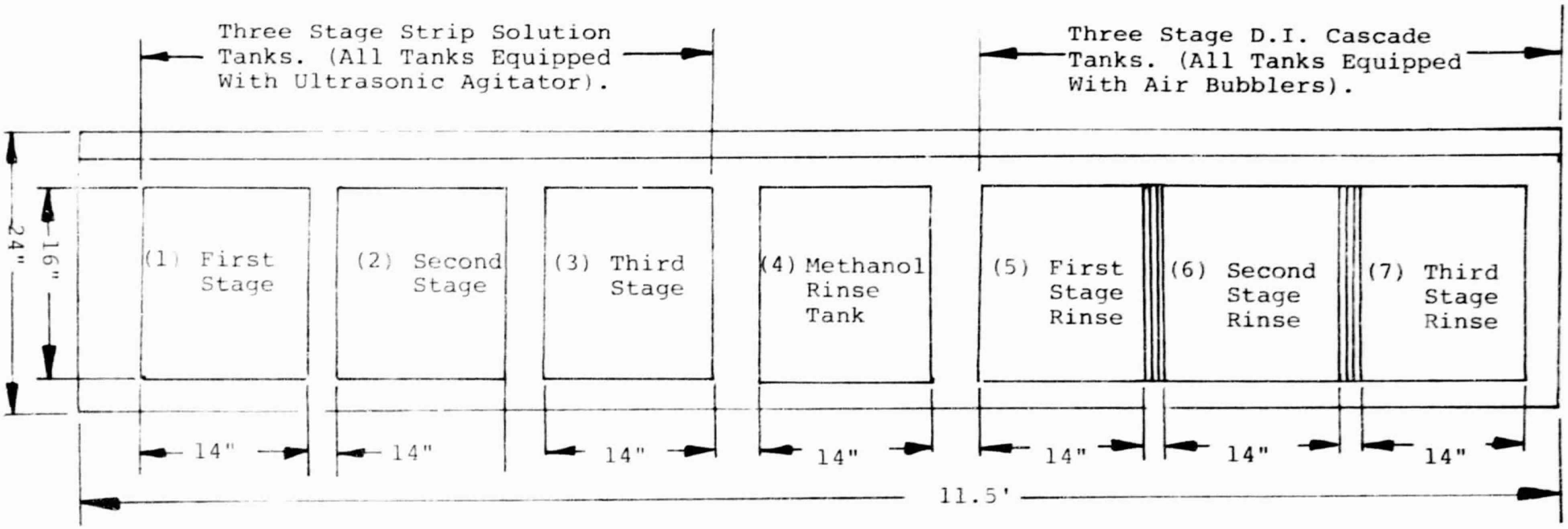
B2.5. Resist Removal (RESREM)

B2.5.1. Design for High Volume Production

A plasma etching method was investigated as an alternative resist removal technique in Task 3 of Phase 2 of the Array Automated Assembly Program (Ref. 9). The results of a preliminary SAMICS cost analysis for the plasma etching process led to the conclusion that it will not meet the 1986 LSA program goals. Consequently, the standard wet chemical resist removal method then in use by Sensor Technology, Inc. will be utilized in the large volume production line of CELLCO with the addition of an automatic wafer handling system. The schematic diagram of this system, not including the automatic material handling system, is depicted in Figure 45. The process equipment consists of chemical solution tanks, and an automated material handling system. This resist removal process is described below.

B2.5.1.1. Three Stage Resist Removal System

Three 16" x 14" x 10" process tanks are filled with resist removal solution.



DESIGN SPECIFICATIONS

(A) Depth Of Tank = 10" + (3 Exhaust Outlet)

(B) Material = Stainless Steel Tanks For (1), (2), (3)
Polyproplene Tanks For (4), (5), (6), (7)

(C) Solution Transfer Pump Between (3) and (2); (2) and (1)

(D) All Tanks Require Drain Cleaning

Figure 45. Schematic Layout of Wet Chemical Resist Removal System (3,600 wafers/hr. capacity)

After one hour of processing wafers in the three stage resist removal system, the solution in the first tank is drained. The solution in the second tank is transferred to the first tank, and solution in the third tank is transferred to the second tank. Clean resist removal solution is then supplied to the third tank. In this manner, the third process tank always contains clean solution relative to the other two tanks. Each tank can process up to six wafer carriers each of which has a 25 wafer capacity. An additional 30 seconds per tank must be allotted for transfer time, which leads to a total process time of 2.5 minutes per tank. The throughput rate for this system is 3600 wafers/hr.

B2.5.1.2. Methanol Rinse Tank

After the wafers undergo resist removal, they are transferred to a 16" x 14" x 10" methanol rinse tank. The processing time at the methanol rinse tank is identical to that of the resist removal tanks to preserve process continuity.

B2.5.1.3. Three Stage D.I. Rinse Tanks

The final step of this process is a three stage cascade D.I. water rinse. The processing time at each of the three tanks is two minutes. An additional 30 seconds per tank must be allotted for transfer time. Consequently, the total processing time per tank is 2.5 minutes.

B2.5.2. Supporting Data for Format A

B2.5.2.1. Equipment Cost Factor

The equipment cost of $10,000 for the resist removal process was estimated directly from current equipment prices in the commercial market. The carrier transfer mechanism was estimated to be $2,000. The useful equipment lifetime is seven years as recommended by IPEG.

B2.5.2.2. Labor and Floor Space

The floor space requirement of 64 sq. ft. was estimated directly from the schematic diagram shown in Figure 45. One operator is sufficient to operate four complete systems without any difficulty, provided that an automated material handling system is included within the resist removal system. The remaining direct labor requirements are identical to the wafer surface preparation task.

B2.5.2.3. Commodities and Utilities

All material and utility consumption rates were estimated on the basis of actual experimental data.

All input data utilized in the process cost computation of the resist removal process may be located in the appropriate Format A of Appendix II.

B2.6. Hexagonal Laserscribing Process (HEXLS)

B2.6.1. Design for High Volume Production

An indepth study of laserscribing and holing automation was performed in Task 12 of Phase 2 of the Array Automated Assembly Program (Ref. 9). The conceptual design for the serial flow laserscribing system was developed by a subcontractor, Quantronix Corporation.

Figure 46 shows the major components of the Serial Flow laserscribing system. This unit is comprised of 2 loaders, 2 aligners, 3 dual beam lasers, 4 trepanning lasers, 4 wafer crackers and a moving surface onto which are mounted, at evenly spaced intervals, wafer holding chucks. One wafer at a time is removed from its storage container and transferred onto a holding chuck which carries the wafer through the scribing process. The wafer is moved along by conveyor to the wafer aligner where the wafer grid lines are oriented in preparation for scribing. The wafer is then passed under a dual beam laser whose beams are aligned and focused so that two

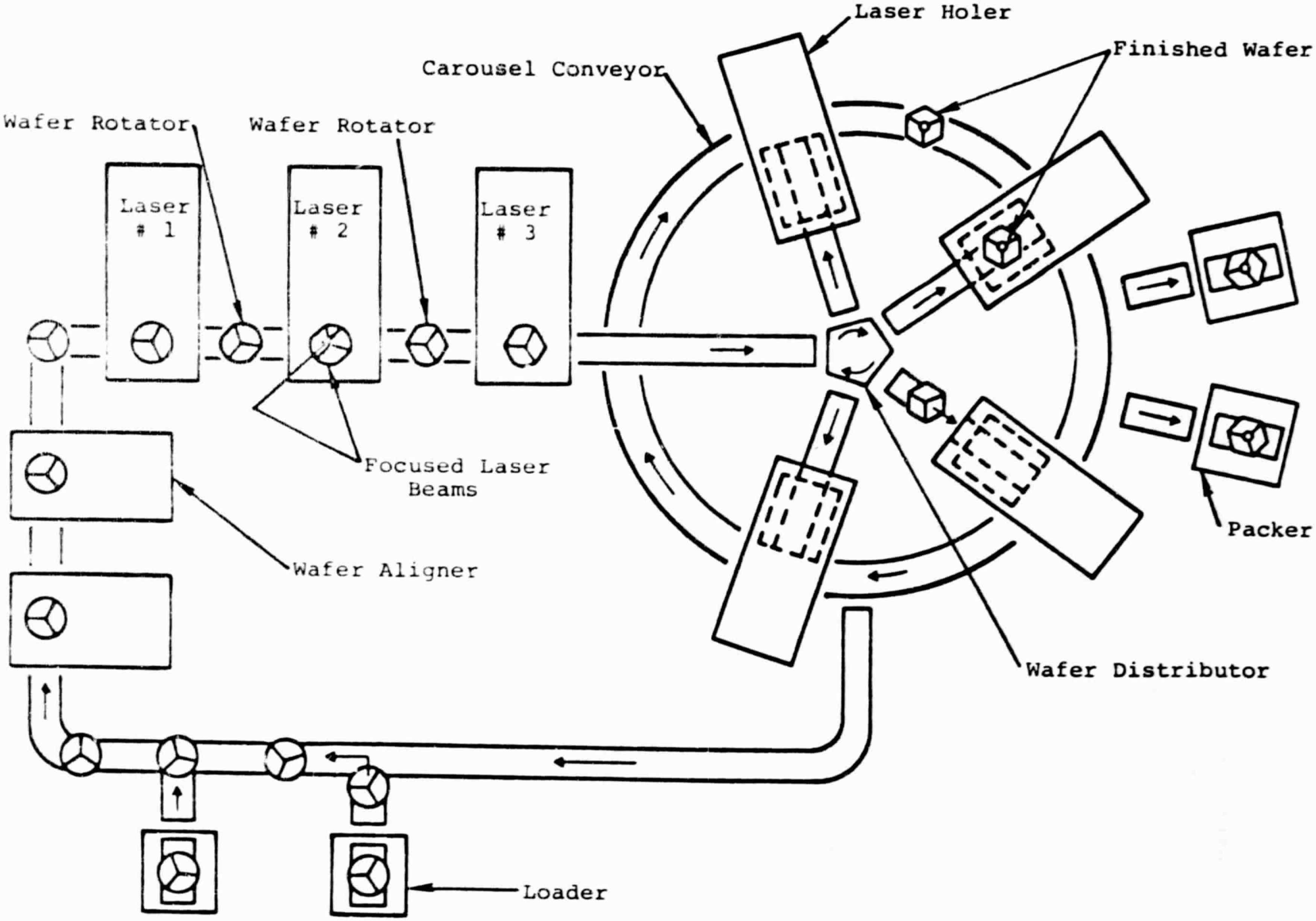


Figure 46. Serial Flow Laserscribe System for 7200 Wafers Per Hour.

parallel sides of a hexagon are simultaneously scribed. The wafer is then moved at constant speed to the chuck rotator which is indexed to turn the wafer 60^{o}. The wafer is next moved to laser number 2 where the second pair of parallel sides is scribed. The partly scribed wafer is again rotated 60^{o} and the last pair of parallel sides is scribed by laser number 3. The hexagon scribed wafer is next off-loaded from the conveyor and is distributed to the trepanner/cracker units. Since it takes four times as long to produce holes as to scribe the hexagon, four trepanner/cracker units are needed for each hex scriber set of three lasers.

The finished wafers are finally off-loaded from the trepanner/cracker and loaded onto the carousel conveyor which carries them to the wafer scanner where each wafer is examined for completeness of scribing. Acceptable wafers are returned to storage containers; defective wafers are diverted to the defective wafer packer. The empty chucks are transferred to the return conveyor and to the loader to receive the next wafer. The scrap silicon, meanwhile, is collected and returned to the recycling station.

The serial flow laserscribing system contains several subunits which are utilized for manipulation and transfer of wafers through the scribing operation. These subunits include: (1) two wafer loaders, (2) wafer aligner, (3) wafer chuck/cracker, (4) wafer rotator, and finally, (5) wafer distribution unit.

The present state of laser development allows scribing silicon wafers at speeds up to 4 in./sec. and trepanning wafers at speeds up to 0.1 in./sec. It is

expected that laser output will improve by 4 times in 1986, so that scribing speeds of 10 in./sec. with a dual beam laser will be feasible. The wafer throughput will be 2 wafers per second since the conveyor speed is 10 in./sec. and the wafers are spaced on 5 inch centers. Wafer throughput is 7200 wafers/hr.

B2.6.2. Supporting Data for Format A

The process cost estimation for the hexagonal laserscribing process entailed the following cost elements.

B2.6.2.1. Equipment Cost Factors

The equipment prices are in terms of 1978 cents, and are based on the criterion that 15 complete systems will be manufactured. The subunit costs are given below.

Subunit	Qty.	Unit Price ($1000)	Total ($1000)
Laser	7	30	210
Loader	2	3	6
Aligner	2	3	6
Packer	2	3.5	7
Distributor	1	5	5
Carousel Conveyor	1	15	15
Rotator	3	2	6
Main Conveyor	1	40	40
Sensor	1	5	5
Wafer Chuck	40	0.5	20
	Total (Thousand $'s)		320

B2.6.2.2. Labor and Floor Space

The floor space requirement takes into consideration the actual floor space utilized by the entire laserscribing system, and also an additional three feet

of clearance around the unit for working space. One operator will operate one unit per shift. The remaining direct labor requirements are assumed to be identical to the wafer surface preparation task.

B2.6.2.3. Commodities and Utilities

B2.6.2.3.1. Spare Parts

Eight percent of the equipment cost is allocated for spare parts. This will cover the spare-part requirement for the lifetime of the unit, which is six years.

B2.6.2.3.2. Cooling Water

7 gals/min. of cooling water is required for an input of 8 KW of electrical power. For this unit, which requires an input of 80 KW of electrical power, the coolant requirement becomes 70 gals/min. By assuming an improvement in coolant efficiency by 1986, the coolant requirement will be reduced to 42 gals/min. per unit.

B2.6.2.3.3. Electric Power

The present electrical power conversion efficiency of lasers is 0.29%. The laser power needed to scribe at a rate of 10 in./sec. is 32 watts/beam which implies that an electrical power input of 11.03 KW/beam is required. Since each laserscribing machine utilizes 10 beams, the power requirement is 111 KW/machine. By assuming that the laser efficiency will increase to 0.5% by 1986, the required electrical power input will be 64 KW/machine. An additional 3 KW of electrical power must be considered for support electronics, thus bringing the total power requirement per unit to 67 KW.

B2.7. Solder Flow and Flux Removal (SDFLW)

B2.7.1. Design for High Volume Production

A feasibility study of a high volume solder coating process has been performed in Task 10 of Phase 2 of the Array Automated Assembly Program (Ref. 6). In this study, it was found that the solder dipping method is capable of performing at a high throughput rate. Consequently, a 3600 wafer/hr. conceptual solder dipping and flux removal system was designed for use in the high volume production line of the CELLCO firm. The schematic diagram of the conceptual solder dipping and flux removal system is shown in Figure 47. The sequential operation of this system is discussed below:

B2.7.1.1. Flux Application

A standard dipping procedure of silicon wafers into soluble flux is performed initially.

B2.7.1.2. Preheating Silicon Wafers

Preheating silicon wafers prior to immersion into the solder bath is highly recommended as a precautionary measure against thermal shock. The recommended preheating temperature is between 150 and 200^{o}F.

B2.7.1.3. Solder Dipping

A fully loaded Fluoroware Teflon PFA wafer carrier is submerged into a solder bath which is maintained at a temperature of 475^{o} $\pm$25^{o}F. The duration of this dipping procedure is 5-10 seconds. The solder bath must be an overflow bath in order to achieve steady solder flow at a uniform temperature.

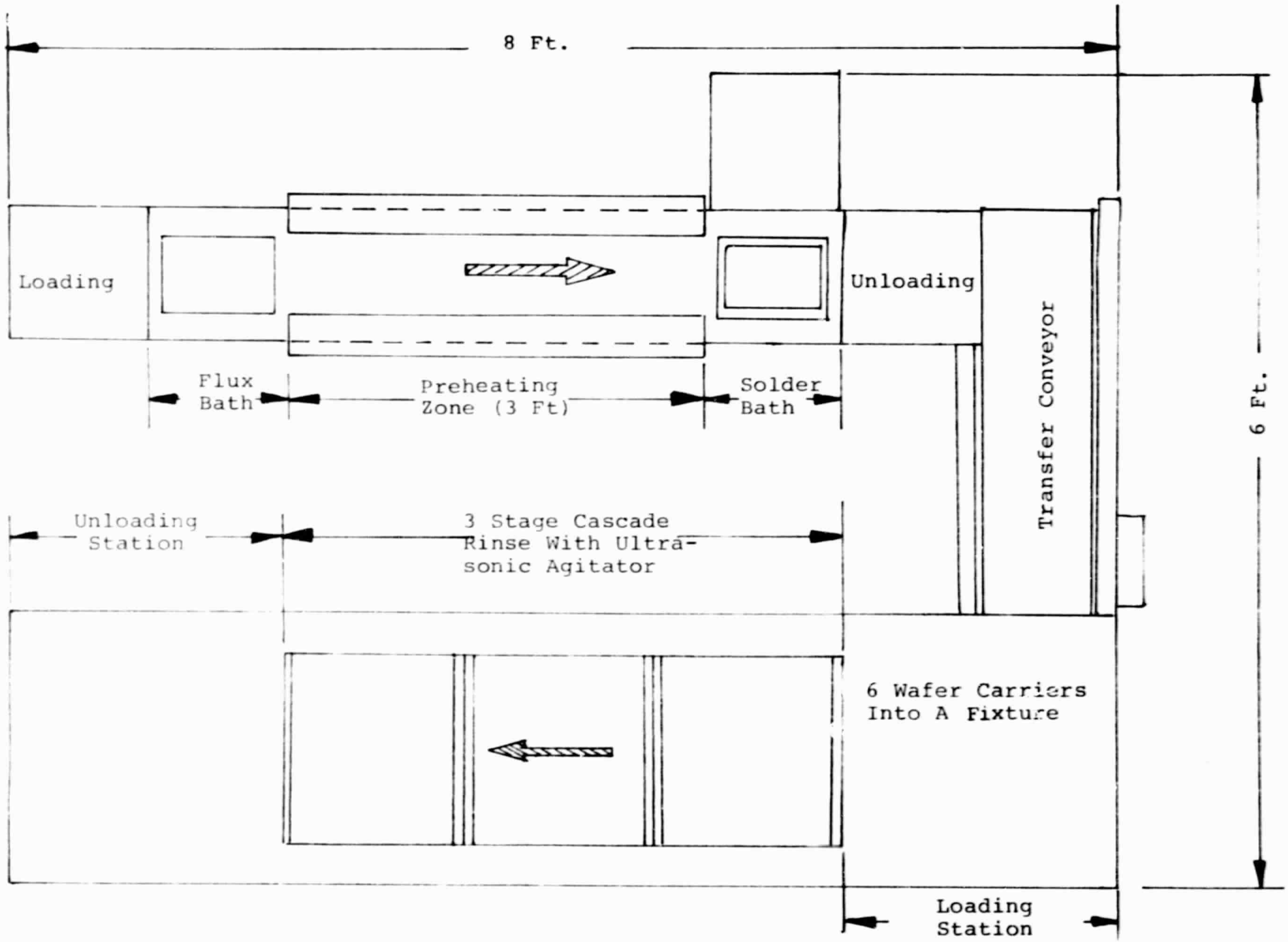


Figure 47. Conceptual Solder Coating and Flux Removal System (3600 wafers/hr.)

B2.7.1.4. Flux Cleaning

Since the flux utilized in this process is water soluble, a three-stage cascade D.I. wafer rinse will suffice for flux removal. It was found experimentally that an ultrasonic agitator in conjunction with a D.I. water rinse will remove flux far more efficiently than D.I. water alone. By considering transfer times, the processing time is 2.5 minutes at each tank in the three-stage cascade D.I. water rinse system. The D.I. water temperature should be 90°C, so as to preclude the need for a separate drying cycle.

B2.7.2. Supporting Data for Format A

The process cost estimation for the solder flow and flux removal process entailed the following cost elements.

B2.7.2.1. Process Characteristics

The throughput rate for this process is 60 wafers/min. The average time spent at this station is 13.33 minutes. The machine "up" time fraction is assumed to be 0.875 by taking into account one hour of machine downtime per shift.

B2.7.2.2. Equipment Cost Factors

The estimated cost of the conceptual high volume throughput solder flow and flux removal system is as follows:

Soldering process	\$ 9,000
Three-stage cascade rinse	11,500
Material handling	5,000
Total	\$25,500

B2.7.2.3. Labor and Floor Space

The estimated floor space requirement which includes working space is 80 sq. ft. One operator can operate four units. All remaining direct labor requirements are identical to the wafer surface preparation task.

B2.7.2.4. Commodities and Utilities

The chemical and direct material consumption rates are scaled up proportionately from the values used in the current production line. The electrical power consumption rate for the conceptual high volume throughput solder flow and flux removal system has been estimated as follows:

Preheater	3 KW
Solder bath	5 KW
Ultrasonic generator	3 KW
D.I. water heater	3 KW
Material handling	1.5 KW
Total	15.5 KW

All input data utilized for this process cost computation may be located in the appropriate Format A of Appendix II.

B2.8. Antireflective Coating (ARCT)

B2.8.1. Design for High Volume Production

Silicon nitride plasma deposited A.R. coatings were studied in Task 8 of Phase 2 of the Array Automated Assembly Program (Ref. 6). The LFE System 8000 silicon nitride plasma depositor shown in Figure 48 was selected for use in this study.

The LFE System 8000 is composed of a vacuum processing chamber which contains five separate process zones with the wafer receiving 20% of its total film in each zone in a sequential manner. The wafer passes through a vacuum lock at the entrance of the chamber and through an

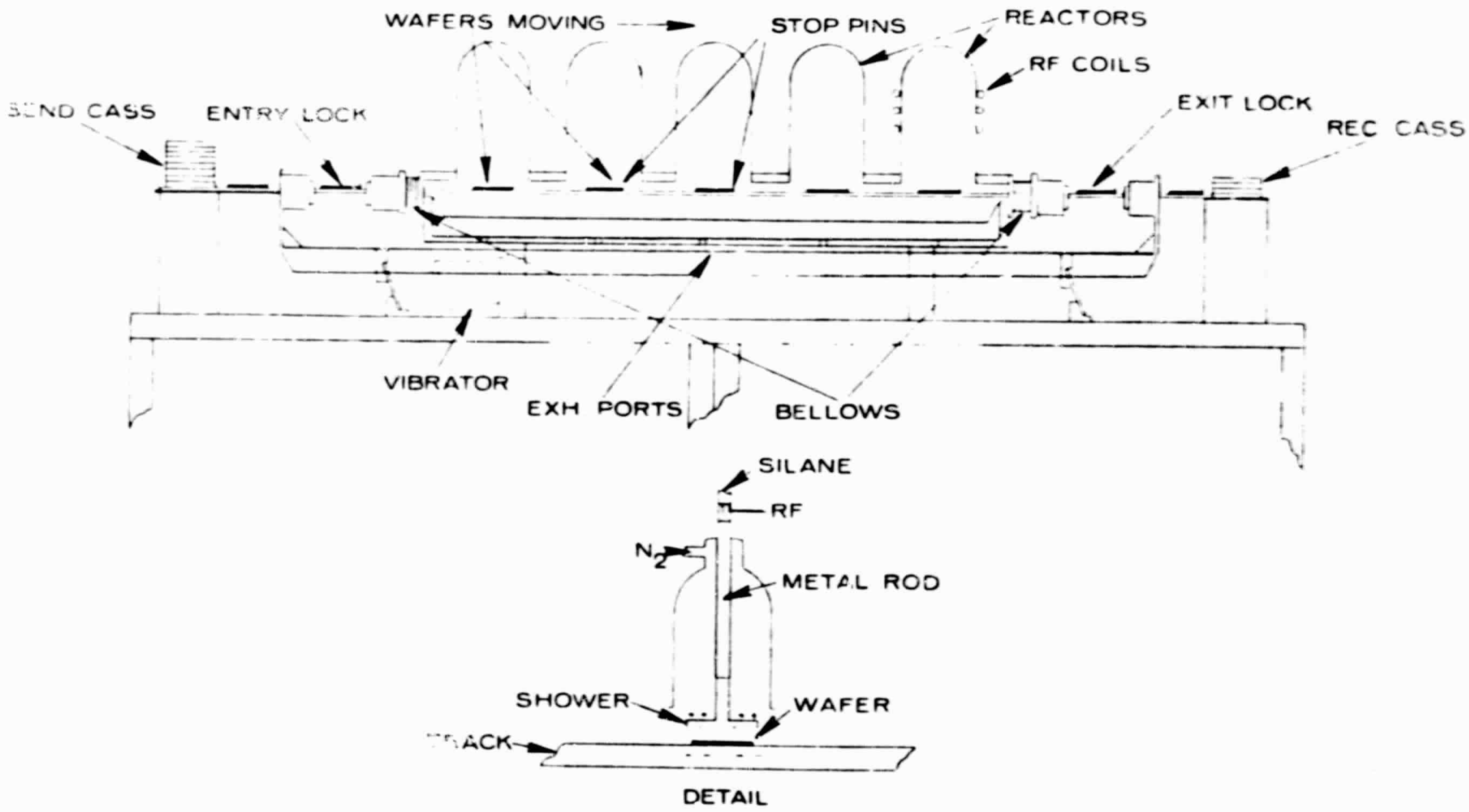


Figure 48. LFE 8000 System for Silicon Nitride Antireflective Coating.

identical vacuum lock after it has been processed through all five process locations. Upon completion of this procedure, a fully coated wafer will emerge every 120 seconds. This throughput rate will need to undergo considerable improvement in order to meet the 1986 LSA program goals. During the course of this study, it was concluded that the LFE System 8000 could be utilized for large volume production by simply performing minor equipment modifications.

The key design modifications which will lead to an enhanced wafer throughput are discussed below.

B2.8.1.1. The wafer velocity on the process track should be increased and the positioning control improved. It is imperative that the wafer velocity on the process track be increased from 2 in./sec. to 3 in./sec. This can be achieved by redesigning the vibratory subsystem so that an upper velocity limit is established. Since each wafer must be accurately positioned in the process zone in order to obtain the proper degree of film uniformity, it is necessary to provide a "stop pin" on the process track. The stop-pins retreat into the track during wafer movement and then resurface when the wafer movement ceases. The wafer movement is controlled by a microprocessor which receives wafer positioning data from the capacitive sensors which are imbedded in the process track. The microprocessor controls the turn-on of the vibratory mechanism and the stop-pins in accordance with the particular timing sequence under consideration and wafer positioning information.

B2.8.1.2. The wafer transition time through the vacuum locks should be decreased. The transition time of a single wafer from the sender to the vacuum lock and then

C-3

from the vacuum lock to the process chamber is 30 seconds for the present system. In order to move five wafers through this sequential transition operation within a 40 second time period, a new design is required. This new design has a cassette mechanism located within the entry lock (and also the exit lock) allowing for a buffer of five wafers in the "ready" zones, namely, the entry and exit locks. As each wafer moves into the lock cassette, the cassette will index up (or down) one notch in preparation for the next wafer until all five wafers are received (or dispatched in the case of the exit lock).

By adopting the above mentioned equipment modifications, a wafer throughput rate of 300 wafers/hr. will be achieved. Despite the fact that this enhanced wafer throughput rate is still not suitable for the 1986 standard industry, it is useful to obtain this process cost as a means of comparing competing A.R. coating methods. Consequently, the modified LFE System 8000 was utilized in the high volume production line of the CELLCO firm.

B2.8.2. Supporting Data for Format A

The process cost estimation for the antireflective coating process entailed the following cost elements.

B2.8.2.1. Equipment

The modifications which will take place are: (1) a new vibratory conveyor system, (2) a new buffer cassette at the entry and exit locks, and (3) a larger microprocessor. The estimated cost of the modified system will be $14,000 provided that more than 20 complete units are ordered. At less than 20 units the cost becomes prohibitive.

B2.8.2.2. Floor Space and Labor

The floor space estimation, including working space is 40 sq. ft. It is assumed that one operator can handle up to 10 units, since the equipment is fully automated and processing control is exercised exclusively through a microprocessor. Other direct labor requirements are identical to the wafer surface preparation task.

B2.8.2.3. Utilities and Commodities

Utilities - Since the deposition rate will remain unchanged, the power increase will be due exclusively to the wafer handling unit. It was estimated that the total electric power consumption rate will increase by 25%. The power requirement of the modified equipment will therefore be 10.29 KW.

Materials - Since the gas consumption rate is contingent upon the film deposition rate, the gas consumption rate will remain identical to that of the current module.

All input data utilized for this process cost computation may be located in the appropriate Format A of Appendix II.

B2.9. Cell Testing (CELTEST)

B2.9.1. Design for High Volume Production

An automated solar cell testing system has been studied in Tasks (1) and (13) of Phase 2 of the Array Automated Assembly Program (Ref. 6). On the basis of these studies, the conceptual automated solar cell testing system shown in Figure 49 was designed. This solar cell testing system is able to test and group 3600 solar cells per hour. The subunits which comprise this system are described below.

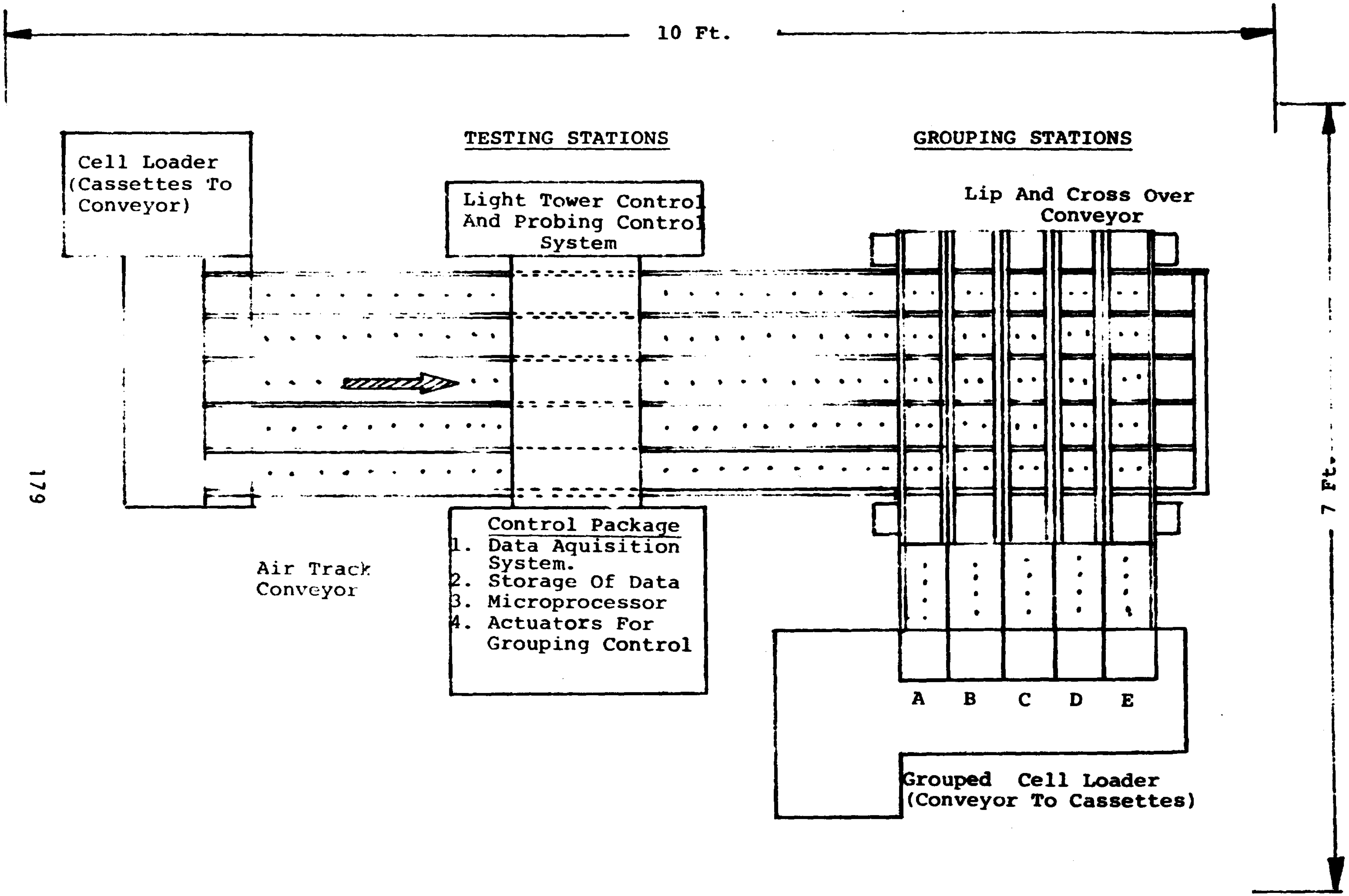


Figure 49. Conceptual Design of Automatic Solar Cell Test System (3600 wafers/hr. capacity).

B2.9.1.1. Cell Loader

Five cassettes which contain 25 solar cells each are loaded onto solar cell feeders. One solar cell from each cassette is simultaneously loaded onto one of five pneumatic conveyors. The time for simultaneously loading 5 solar cells is 5 seconds. Therefore, the throughput rate for this process step is 1 solar cell/sec.

B2.9.1.2. Light Tower

One 650W Xenon light tower is located at each of the 5 conveyor tracks. Each light tower is equipped with a suitable reflector and power regulator for maintaining uniform light intensity. A stopping mechanism will halt the motion of the conveyor for 5 seconds when the solar cells arrive at the light towers, so that electrical performance tests may be performed.

B2.9.1.3. Probing Mechanism and Data Acquisition

When a solar cell stops at the light tower, a probing mechanism will make contact with it. Electrical performance data is subsequently recorded in the microprocessor unit through electronic simulator sampler circuits. The microprocessor will analyze and store this data, as well as compute the maximum power point. It also exercises control over the stopping mechanism in the grouping station.

B2.9.1.4. Grouping Station

Incoming solar cells will stop at one of five stopping stations on the basis of input data supplied by the microprocessor. A cross pneumatic conveyor will then activate solar cell motion in the transverse direction, until the solar cell arrives at the storage area.

B2.9.1.5. Cell Loader

Five cassettes are loaded with grouped solar cells at this station. The loaded cassettes are then transported to the module fabrication station. Rejected solar cells are stored at a separate storage area.

B2.9.2. Supporting Data for Format A

The process cost estimation for the cell testing process entailed the following cost elements.

B2.9.2.1. Equipment

The estimated cost of each machine element is as follows:

Loader	$ 2,500
Conveyors	1,000
Light tower and 2 probes	18,500
Grouping station	8,000
Unloader	2,500
Data Acquisition	15,000
	$47,500

B2.9.2.2. Floor Space and Labor

Floor space, including work space, was estimated to be 70 sq. ft. One operator is sufficient to operate four units. The remaining direct labor requirements are identical to the wafer surface preparation task.

B2.9.2.3. Utilities and Commodities

The electrical power requirement for this process was estimated as 8.25 KW. There are no commodity requirements.

The input data utilized for this process cost computation may be located in the appropriate Format A of Appendix II.

B3. Price Computation

The price of a solar cell was determined after all the data required for each Format A were compiled. The cost computation proceeded in accordance with the procedure outlined for the process worksheet and company worksheet described in Reference 2. Additional expense item information, which was not included in the cost account catalog in Reference 3, was found in the then available market price literature.

The total cost incurred at each solar cell process step was manually calculated and can be found in Table 28. The cost for each process was further subdivided into independent elements which consist of the cost in terms of 1980 cents per peak watt for space, labor, materials and utilities.

B3.1. Discussion of Results

The total added value for CELLCO is 27.719 cents per peak watt in 1980 cents. This value is slightly higher than the IPEG price goal of 26.18 cents per peak watt. As shown in Table 28, metallization (step C-4) and A.R. coating (step C-8) processes claim a disproportionate share of the total cost for CELLCO. The major shortcoming of the current electroless nickel plating metallization process is its use of costly materials. The major shortcoming of the silicon nitride plasma deposition A.R. coating process resides with its high equipment cost. It is highly recommended that future work should focus on reducing the costs of the metallization and A.R. coating processes. Two related candidate procedures exhibiting high potential for success in this task are spray-on metallization and spray-on A.R. coating. Results of non-automated experiments indicate high quality.

Table 28. CELLCO Process Cost Summary in 1980 Cents per Peak Watt.

PROCESS NUMBER	PROCESS REFERENT	EQUIPMENT	FLOOR SPACE	LABOR	MATERIAL & BY-PRODUCTS	UTILITIES	TOTAL
C-1	WFSURPR	0.280	0.101	0.616	1.092	0.266	2.355
C-2	JUNF	0.770	0.244	0.798	1.680	0.897	4.389
C-3	FSPP	0.179	0.154	0.378	0.594	0.070	1.375
C-4	ELNIPL	0.118	0.053	0.602	5.334*	0.193	6.300*
C-5	RESREM	0.038	0.024	0.308	2.290	0.153	2.813
C-6	HEXLS	0.378	0.042	0.490	0.006	0.172	1.088
C-7	SDFLW	0.070	0.029	0.294	2.660	0.298	3.351
C-8	ARCT	2.605*	0.174	1.316	1.120	0.384	5.599*
C-9	CELLTEST	0.140	0.025	0.259	0.0	0.025	0.449
TOTAL		4.578	0.846	5.061	14.776	2.458	27.719

*Highest Cost Elements

C. MODULCO Firm

C1. Company Description

The MODULCO firm is a model company in the 1986 standard industry which fabricates solar cell modules from solar cells. The annual production quantity for this company is 2.222 million modules per year, which is equivalent to 200 MW per year.

The module assembly process sequence depicted in Figure 50 was selected for MODULCO on the basis of work performed in Tasks (11), (14), and (17) of this program for Phase 2 of the Array Automated Assembly Task (Ref. 6). The conceptual layout of the MODULCO plant is shown in Figure 51.

A brief description of each of the seven selected processes utilized in the MODULCO model plant is given below.

(M-1) Solar Cell Interconnection (INCON)
In this process, solar cells are interconnected with the use of a flexible printed circuit sheet.

(M-2) Module Lay-up (MDLAYUP)
Interconnected cells are layed-up with other materials for lamination. The arrangement for lay-up is glass/PVB/interconnected solar cells/PVB/Mylar.

(M-3) Degassing Process (DEGAS)
In this process step, module layers are heated to a predesignated temperature. Following the degassing procedure, module layers are placed into a special fixture, which is subsequently transported by conveyor to the autoclave process.

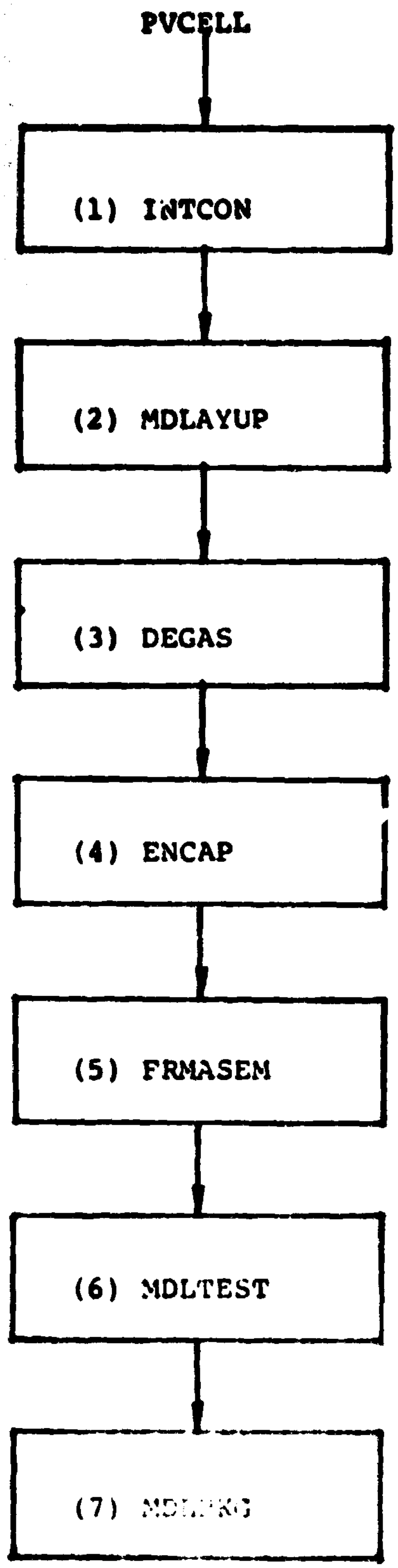


Figure 50. Flow Diagram for MODULCO Processes.

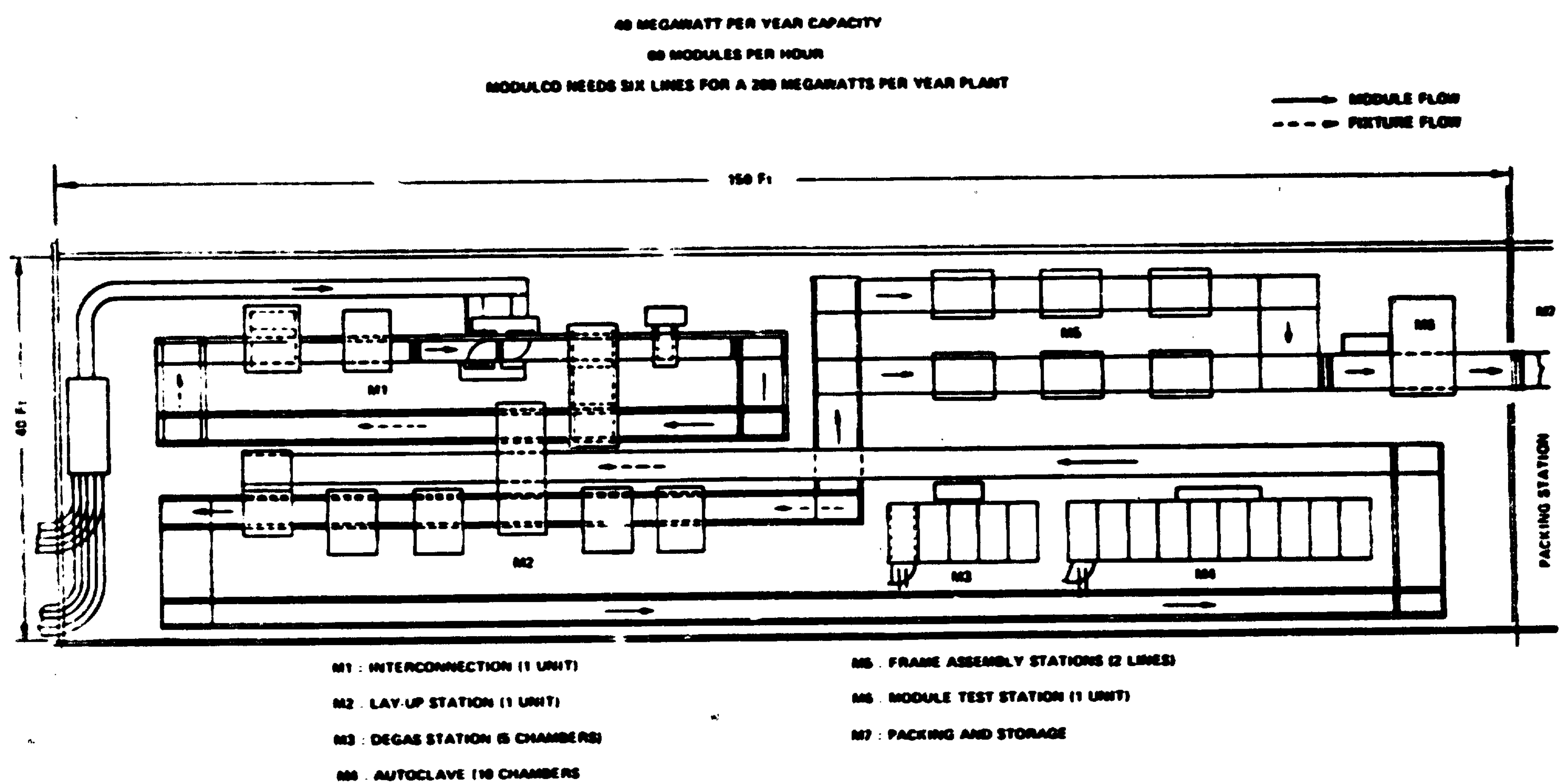


Figure 51. Photowatt/Sensor Technology, MODULCO Production Line.

(M-4) Autoclave Encapsulation (ENCAP)
The encapsulation process completes the module lamination by heating the module layers under low pressure in an autoclave.

(M-5) Frame Assembly (FRMASEM)
The laminated module is framed in an aluminum frame with the use of a suitable sealant material. Terminals are then mounted onto the aluminum frame, for connection with the module terminal wires.

(M-6) Module Testing (MDLTEST)
The electrical performance of the framed modules is evaluated at this process step.

(M-7) Packing and Storage (MDLPKG)
Modules are prepared for shipment at this process step.

The Photowatt/Sensor Technology MODULCO plant was designed to produce approximately 40 MW per year, which is 60 modules/hr. Six production lines will therefore be required to produce 200 megawatts per year which amounts to 40 percent of the total market.

C2. Process Description, Format A

C2.1. Cell Interconnection (INTCON)

C2.1.1. Design for High Volume Production

The conceptual production line for the interconnection process is shown in Figure 52.

C2.1.1.1. Equipment Description

Carrier Fixture - The special carrier fixture utilized in this process is shown in Figure 53. This carrier fixture is composed of a base frame, bottom plunger plate, and top cover plate. A flexible printed circuit sheet

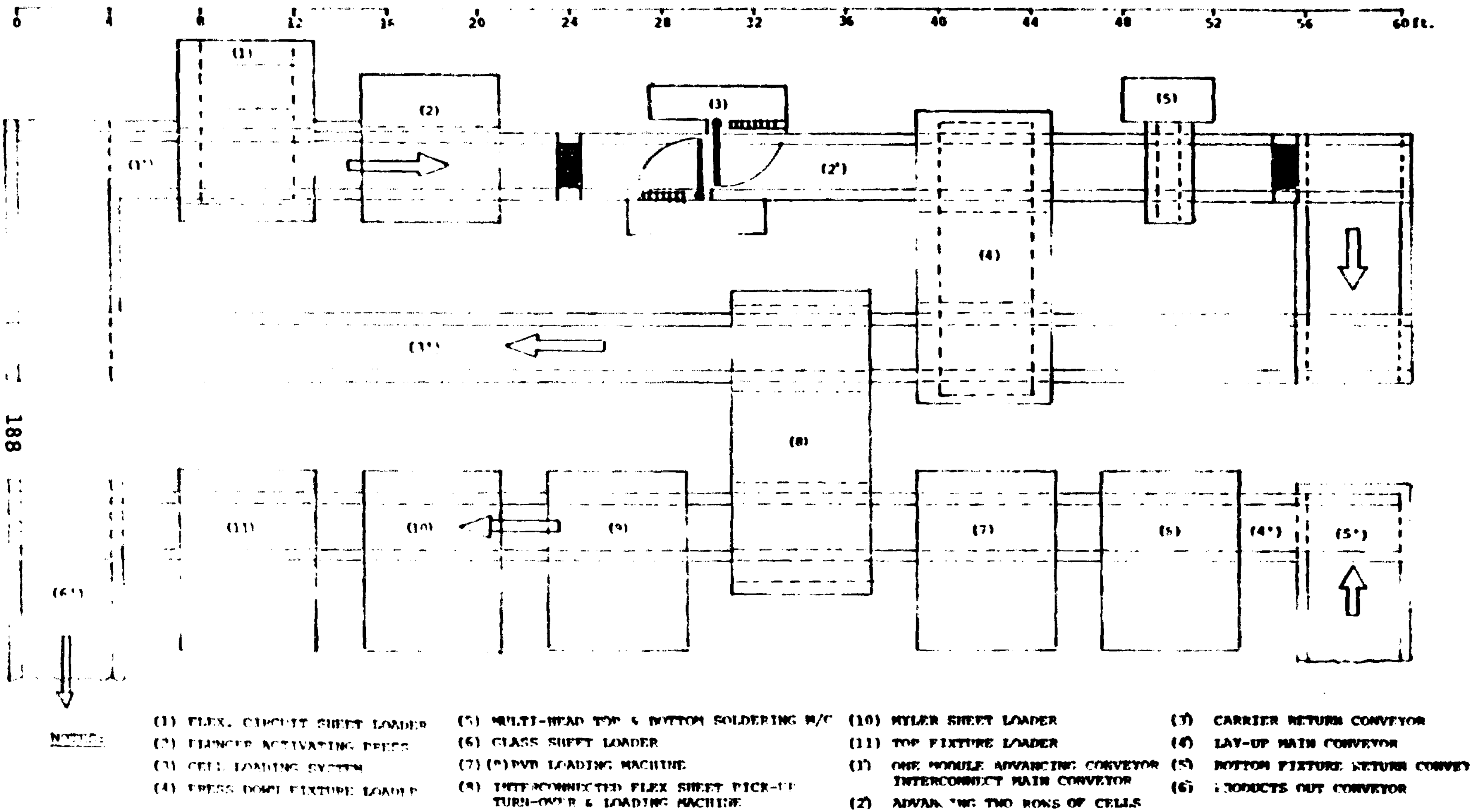


Figure 52. Layout of Module Fabrication Line 1 Interconnection and Lay-up Stations (60 modules/hr.).

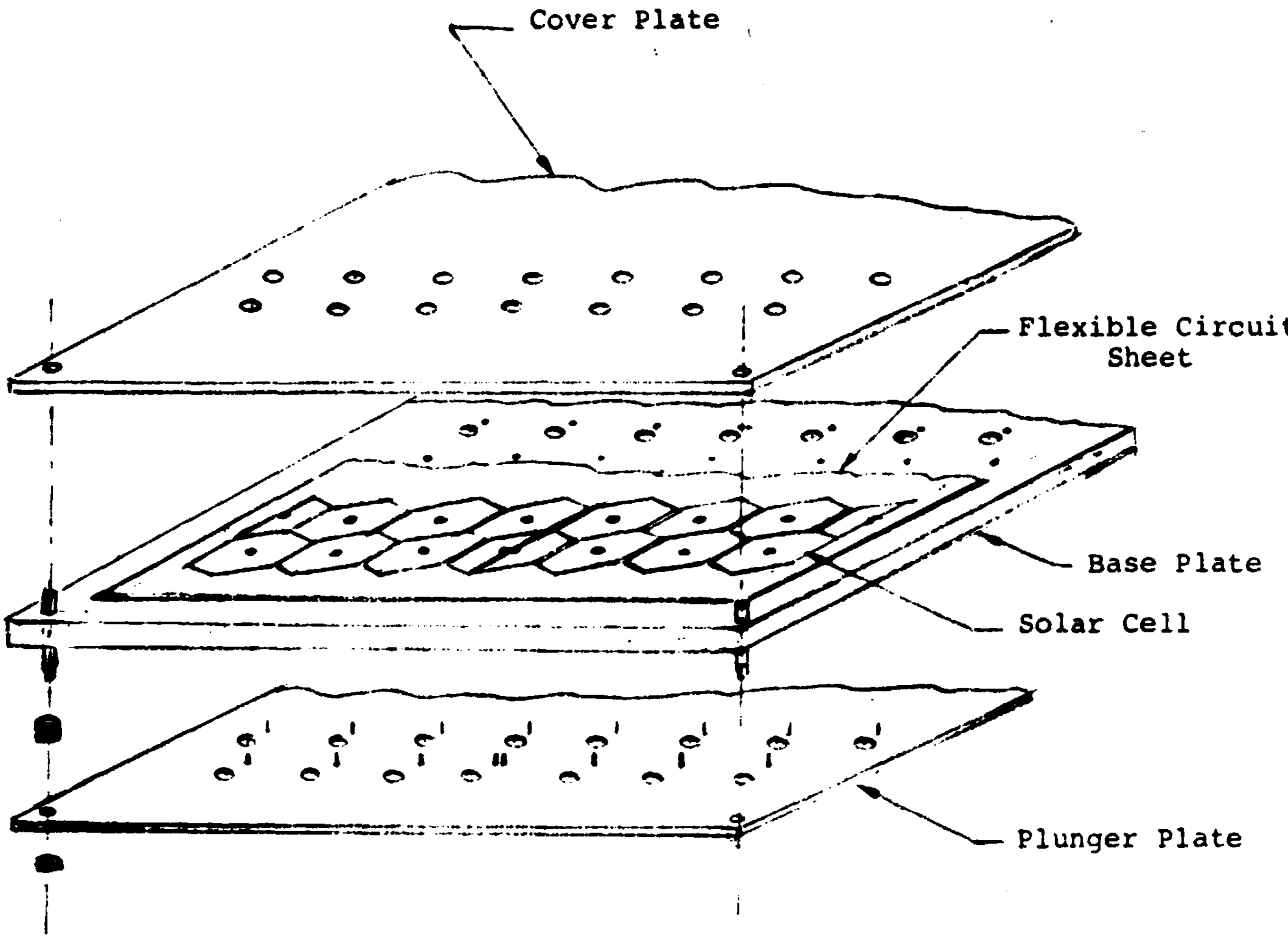


Figure 53. Special Carrier Fixture for Module Interconnection.

will be situated on top of the base frame, which is interspersed with holes so that it may easily be perforated with plungers. This configuration will also permit the soldering iron tip to reach the back contact points. The bottom plunger plate is equipped with a series of plungers fastened at the front contact tab locations. This plate is connected to the base frame by a spring which enables the plungers to puncture the base frame when a downward pressure is applied at the base frame. The end result of this action is that the flexible printed circuit sheet tabs are forced into an upright position. During this entire operation, the bottom plunger plate is locked into position by a catch mechanism, which releases by spring action only after the completion of all solar cell positions. The bottom plunger plate is also equipped with holes to allow the solder gun tip to reach the back contact tab locations. The purpose of the cover plate is to secure the solar cells in position during the entire soldering operation. All three plates are aligned with the flexible printed circuit sheet by means of alignment pins and holes.

Flexible Printed Circuit Sheet Loader - A standard sheet loader is used to place the flexible printed circuit sheet onto the carrier fixture. The required time cycle for this loading process is 30 seconds.

Plunger Activating Press - The plunger activating press will press down the carrier fixture to activate the plunger plate, which in turn forces all tabs into an upright position. At this point, solar cells may be deposited onto the tabs.

Cell Loader - Two cell loading units are required. Each loader will deposit six full cells and two half cells from solar cell holders to the carrier fixture. A robot arm which has multivacuum pickup cups will pick-up a row of solar cells and then rotate 90^{o}. The solar cells are then deposited onto tabs which are in an upright position. The solar cell deposition time is three seconds per row of six full cells and two half cells.

Cover Plate Loader - The cover plate for the carrier fixture is placed onto the carrier fixture from the return conveyor, after solar cell depositions are completed, and the plunger plate has been released to secure the solar cells for the soldering operation.

Soldering System - The soldering system simultaneously solders both the front and back contacts. Two rows of solar cells are soldered in one operation. Flameless gas soldering tips are used to ensure quick heating without causing gridline degradation.

Conveyors - A total of three conveyors is required for this process. The first conveyor is the one module length advance conveyor, located at station #2. The second conveyor is a belt conveyor which advances two rows of patterned solar cells from Station #3 to Station #5. The last conveyor returns the carrier fixture and the string connections to the lay-up station.

C2.1.1.2. Process Description

The special carrier fixtures are fed into the production line from the return conveyor. The sheet loader (station #1) will load a flexible printed circuit sheet onto a carrier fixture which is then transported to Station #2. At this station, the plunger activating press will press down the carrier fixture to activate the bottom plunger plate. This will cause all plungers to pop-up

through the tab locations. The carrier fixtures are next transferred to Station #3 via conveyor #2. The solar cell deposition system (Station #3) will deposit two rows of solar cells at each plunger pin. The time for depositing these two rows of solar cells is 5 seconds, so that all the solar cells for one module are deposited in one minute.

Following the completion of all solar cell depositions, the carrier fixture is advanced to Station #4, where the cover plate is placed over the carrier fixture to secure the position of the solar cells. At this time, the plunger plate is lowered by releasing the ratchet. The next process step is the soldering operation (Station #5). Each soldering cycle encompasses five seconds. A soldering cycle consists of soldering two rows of the solar cell interconnection pattern. The time for completion of module interconnection is 60 seconds. The interconnected module is transferred by return conveyor to Station #4, where the cover plate is removed from the special carrier fixture and then transported to the lay-up station. The special carrier fixture is returned to the first station.

C2.1.2. Supporting Data for Format A

C2.1.2.1. Process Characteristics

The throughput rate was designed to be one module per minute. The yield factor for this process is assumed to be 98.5%. The average conveyor speed is four feet per minute, and the conveyor length is 92 feet. The average time spent at this station is 28 minutes. The process usage time fraction was assumed to be 0.875 by taking into consideration an average machine down-time of one hour per shift.

C2.1.2.2. Equipment Cost Factor

The cost estimation for each system component is listed below:

FCS loader	$ 5,000
Plunger activation press	10,000
Cell loader	20,000
Cover plate loader	10,000
Soldering machine	50,000
Total Cost	$95,000
Conveyor #1	$ 3,000
Conveyor #2	5,000
Conveyor #3	10,000
Total Cost	$18,000

Carrier fixture - $100/ea. x 34 units = $3400

The useful lifetime of all equipment is assumed to be seven years, in accordance with Reference (1).

C.2.1.2.3. Labor and Floor Space

The floor space requirement was estimated to be 1400 sq. ft. One operator can operate two complete systems. The remaining labor requirements are listed below:

Production planner	0.02
Maintenance man	0.1
Q.C. inspector	0.1

The above labor requirement specifications apply to all remaining process steps.

C.2.1.2.4. Utilities and Commodities

The direct materials required for this process include flexible printed circuit sheets, and compressed air for the flameless inert gas soldering equipment. For this process, solder is unnecessary since the solder reflow method is used. The electrical power requirement estimation is presented as follows.

Sheet loader	0.4 KW	(½ HP with control)
Plunger press	0.8 KW	(1 HP " ")
Cell loader	0.8 KW	(1 HP " ")
Cover plate loader	0.8 KW	(1 HP " ")
Soldering unit	22.5 KW	(Heater, 1 HP Drive, and control)
Three conveyors	2 KW	(Approx. 1 HP motor per conveyor)
Total Power	27.3 KW	

The process usage factor is 1.0 since this system operates continuously. Additional process data may be found in Format A, in Appendix III.

C2.2. Module Lay-up Process (MDLAYUP)

C2.2.1. Design for High Volume Production

The conceptual production line for the module lay-up process is presented in Figure 52. From this figure it can be seen that stations 6 through 11 are the major constituents of the conceptual module lay-up production line.

C2.2.1.1 Equipment Description

The function of this process is to stack layers of lamination materials. A total of five lamination materials will be stacked with solar cell string assemblies. Consequently, various standard sheet loaders will be utilized along with a one module length advancing conveyor. The only special loading system which will be required is the string assembly loader (Station #8) which transfers string assemblies from the interconnection return conveyor to the lay-up conveyor. The string assembly loader turns over the cell string assemblies during transfer.

A special fixture which plays an important role in the degassing process is denoted as a "vacuum bag". This fixture is composed of a top and bottom chamber, separated by a flexible membrane. Both sections are tightly joined together with a special screw and seal to maintain a vacuum during the degassing process. The precise function of this fixture will be explained in greater detail in the degassing process.

C2.2.1.2. Process Description

The bottom portion of the special fixture vacuum bag will be fed into conveyor #4. While this fixture is being transported by conveyor, the sheet loaders will deposit encapsulation materials and cell string assemblies in the following order: glass, PVB, cell strings, PVB, Mylar, and finally, the upper portion of the special fixture. Each loading station is separated by 4 feet so that the conveyor will advance by one module length in 10 seconds. Since the loading operation itself will take place in 50 seconds, the entire loading cycle will encompass one minute.

C2.2.2. Supporting Data for Format A

C2.2.2.1. Process Characteristics

The production throughput was designed to be 60 modules per hour and the estimated production yield is 0.995. The average time expended at this process step is 15 minutes since the conveyor length is 60 ft. and the average conveyor speed is 4 ft./min. The usage factor for this production line is assumed to be 0.875 by considering one hour of down-time per shift.

C2.2.2.2. Equipment Cost Factors

The equipment cost estimations are presented below:

5 Sheet Loaders ($5,000 ea.)		$25,000
Cell String Assembly Loader		30,000
	Total	$55,000
Conveyor System (60 ft.)		$10,000
120 Fixtures ($100 ea.)		12,000
	Total	$22,000

C2.2.2.3. Floor Space and Labor

The required floor space includes working space, and was estimated to be 840 sq. ft. One operator can operate two production lines, and the remaining labor requirements are identical to the INTCON process.

C2.2.2.4. Utilities and Commodities

The encapsulation materials utilized in this process include glass, PVB, and Mylar. The electrical power requirement for this system was estimated to be 3.78 KW, and the usage factor is 1.0.

Additional process data may be obtained from Format A in Appendix III.

C2.3. Degassing Procedure (DEGAS)

C2.3.1. Design for High Volume Production

C2.3.1.1. Process Function

This process will degass air from module interlayers and then seal the module in a vacuum environment with a special fixture (vacuum bag). The module layers contained in the special fixture are placed into a degassing chamber where degassing occurs by means of a vacuum pump. Following degassing, the fixture is heated up to a specified temperature. The module interlayers are

then sealed by closing the special fixture while it is pressurized from the top fixture through the flexible membrane. Following this procedure, the module is transferred to the autoclave process.

C2.3.1.2. Equipment Description

The conceptual production line for this process is shown in Figure 54. A total of five degassing chambers is utilized to process 60 modules per hour. Each chamber can house six modules, which are processed simultaneously. The time for loading and unloading each chamber will require six minutes, and the degassing process requires 24 minutes. Therefore, the time cycle for this process is 30 minutes per chamber. A single 20 HP vacuum pump will be used to degas each chamber for 6 minutes. In this manner, the vacuum pump can be continuously used for all five chambers. Each chamber is equipped with an I.R. heater to heat the module layers up to 270°F within a ten minute time period. An additional special device required for the degassing chamber is an automatic parameter control unit which controls the pressure of the upper chamber of the fixture after the module is degassed.

C2.3.1.3. Process Description

The special fixture containing the module layers is loaded into the degassing chamber, and connected to the degassing pipe lines. Both the top and bottom fixtures will be connected to the vacuum line for degassing. After degassing both chambers of the fixture, the fixture will be heated up to the proper temperature. The upper chamber, which is separated from the bottom chamber by a flexible membrane, is pressurized with compressed air. The fixture is then disconnected from the degassing line, and is completelv sealed. The fixture is now ready for the autoclave process.

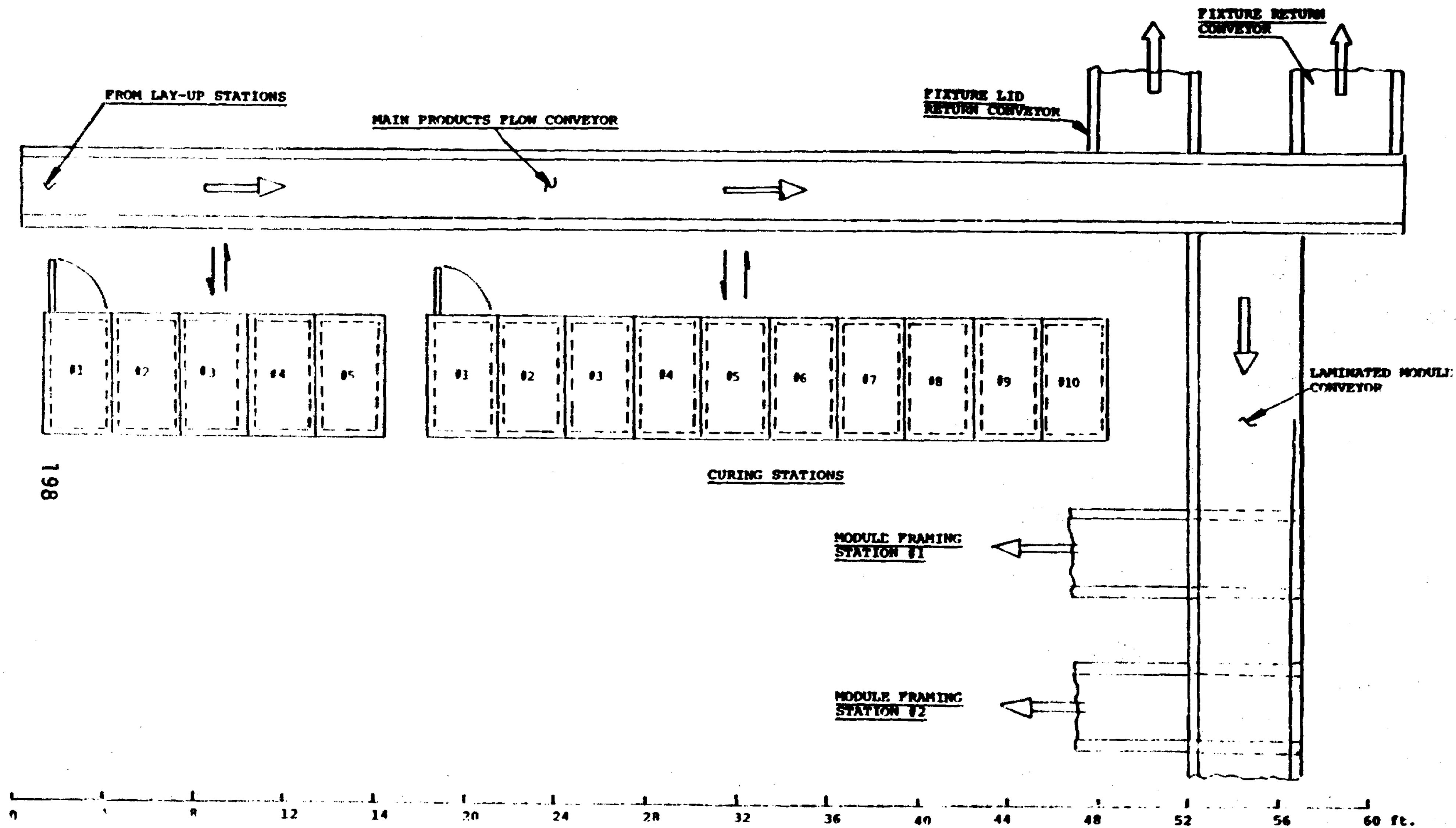


Figure 54. Layout of Module Fabrication Line 11 Module Lamination and Frame Assembly Stations (60 modules/hr).

C2.3.2. Supporting Data for Format A

C2.3.2.1. Process Characteristics

The throughput rate for this process is 60 modules/hr. The expected production yield is 0.985. The average time expended at this station is 30 minutes. The usage fraction is assumed to be 0.875, as in previous processes.

C2.3.2.2. Equipment

The estimated cost for one degassing chamber with the capacity to process 6 modules is $14,400. Since five of these units are necessary, the total equipment cost is $72,000. The conveyor cost was estimated as $10,000.

C2.3.2.3. Floor Space and Labor

The total floor space requirement was estimated from the lay-out drawing to be 280 sq. ft. One operator can handle one production line. The remaining direct labor requirements are assumed to be identical to the INTCON process.

C2.3.2.4. Commodities and Utilities

No special commodities are required for this process. Electrical power is the major utility requirement. Each chamber contains a 25 KW heater. The total electrical power requirement due to these heaters is 125 KW. The usage factor for each heater is 0.3. The vacuum pump has a 22 KW requirement, with a usage factor of 1.0. Consequently, the average system power is 59.5 KW (=125 KW x 0.3 + 22 KW x 1.0).

Additional process data may be obtained from Format A in Appendix III.

C2.4. <u>Encapsulation (ENCAP)</u>

C2.4.1. <u>Design for High Volume Production</u>

C2.4.1.1. <u>Process Function</u>

This process step will secure the laminated layers with the application of heat and pressure for a sufficient amount of time. The minimum temperature which can be used is 275°F, and the maximum pressure which can be used is 50 psig.

C2.4.1.2. <u>Equipment</u>

A total of 10 autoclaves will be used to produce 60 modules/hr. Each autoclave can process 6 modules simultaneously. The heater used in each autoclave should be capable of heating six modules up to 300°F within 20 minutes.

C2.4.1.3. <u>Process Description</u>

Six degassed modules in fixtures are loaded into an autoclave. The loading time for six modules is 3 minutes. The autoclave is heated up to 275°F for 20 minutes. It is then pressurized, and slowly cooled to a lower temperature within a time period of 25 minutes. The total time cycle for this process including loading and unloading times will be 60 minutes. The throughput rate for this system is 60 modules/hr. with the use of 10 autoclaves.

C2.4.2. <u>Supporting Data for Format A</u>

C2.4.2.1. <u>Process Characteristics</u>

The throughput rate of this process was designed to be 60 modules/hr., with an expected production yield of 0.995. The average time expended at this station is 60 minutes, and the usage fraction is assumed to be 0.875.

C2.4.2.2. Equipment Cost Factors

Autoclaves are standard process equipment utilized by safety glass manufacturers. The estimated cost of a single autoclave for the encapsulation process application is $20,000. Upon taking into consideration the necessity for 10 autoclaves and a conveyor system priced at $10,000, the total system cost becomes $210,000.

C2.4.2.3. Floor Space and Labor

The required floor space, including working space, has been estimated from the lay-out drawing in Figure 54 to be 560 sq. ft. One operator can handle ten autoclaves without any difficulty. The remaining direct labor requirements are identical to the INTCON process.

C2.4.2.4. Commodities and Utilities

The required utilities for this process are electricity and compressed air. Four 1 KW I.R. heaters are needed for heating a single module. Therefore, in order to heat six modules per autoclave, 24 KW of electrical power will be required. The usage factor for this heater is 0.5. The electrical power requirement for the complete system thus becomes 120 KW (= 24 KW x 10 x 0.5). The compressed air requirement was estimated to be 960 cu. ft/hr.

Additional process data may be obtained from Format A in Appendix III.

C2.5. Frame Assembly (FRMASEM)

C2.5.1. Design for High Volume Production

C2.5.1.1. Process Function

The purpose of this process step is to perform aluminum framing, followed by the mounting of terminals onto the aluminum frame. The connection of terminal wires to the terminals will complete the module fabrication process.

C2.5.1.2. Equipment

No specialized automated equipment is used for this process. Consequently, manual heat assembly tools, assembly tables, and assembly fixtures will suffice for the operation of this process. Two production lines are used to produce 60 modules/hr. Each production line consists of three substations. These substations will assemble the frame, terminals and wiring in sequence. The layout diagram of these substations is shown in Figure 51.

C2.5.1.3. Process Description

An encapsulated module is fed to the production line via a branch conveyor. One production line which consists of three substations will process one module every two minutes. The first substation trims off excess PVB and Mylar sheet material with trimmers. This operation is performed manually, and requires two minutes. At the second substation, the module is mounted onto an aluminum frame with an assembly fixture and rivet guns. This procedure also requires two minutes. At the final substation, terminals are mounted onto the aluminum frame, and terminal wires are subsequently connected to the terminals all in two minutes. The final product emerging from this process is transferred to the testing station by conveyor. Two production lines will be used to achieve a throughput rate of 60 modules/hr.

C2.5.2. Supporting Data for Format A

C2.5.2.1. Process Characteristics

The throughput rate for each production line is 30 modules/hr. Since two such lines are used, the system throughput is 60 modules/hr. The average time expended at the three substations of each production line is 6 minutes. The usage factor is assumed to be 0.875.

C2.5.2.2. Equipment Cost Factor

The estimated cost of all required tools was $3,000. The estimated cost of the assembly fixtures for both assembly lines was $4,000.

C2.5.2.3. Floor Space and Labor

The required floor space was estimated from the layout diagram in Figure 51 to be 860 sq. ft. Since one assembly worker is needed for each substation, a total of six module assemblers will be required for this process. The remaining direct labor requirements are identical to the INTCON process.

C2.5.2.4. Utilities and Commodities

The direct materials are the aluminum frame, sealant material and terminals. The electrical power requirement is continuous, and was assumed to be 2 KW.

Additional process data may be obtained from Format A in Appendix III.

C2.6. Module Test Procedure (MDTEST)

C2.6.1. Design for High Volume Production

C2.6.1.1. Process Definition

This function of this process is to test module electrical performance, and to print out predesignated electrical performance data.

C2.6.1.2. Equipment Description

A single conveyor will pass through the simulator tower. The data acquisition system will load all input data to the microprocessor through solar simulator circuits. The data is subsequently processed, and printed out for delivery to various departments. An automatic labeling machine is also required to correlate modules with their corresponding data. The schematic lay out for the complete module test system is shown in Figure 51.

C2.6.1.3. Process Description

A fully assembled module is fed to the conveyor every minute. This module is sequentially labeled by number, and then registered at the microprocessor. When the module arrives at the solar simulator tower, the module will be stopped, and probing pins will make contact with the module's terminals. As soon as light reaches the modules, electrical performance data is fed to the microprocessor through the data acquisition system. The data is then analyzed, and all pre-designated data is printed out. The module now transfers to the shipping area via conveyor.

C2.6.2. Supporting Data for Format A

C2.6.2.1. Process Characteristics

The throughput rate for this process was designed to be 60 modules/hr. The process time at this station is six minutes. The usage factor of this system is assumed to be 0.875.

C2.6.2.2. Equipment Cost Factor

The total system cost was estimated as $75,000. This value is based on the automatic data acquisition system studied in this program, as well as Sensor Technology's then existing facility.

C2.6.2.3. Floor Space and Labor

One operator is capable of operating two module test systems. Remaining direct labor requirements are identical to previous processes. Floor space, including work space, was estimated to be 128 sq. ft.

C2.6.2.4. Commodities and Utilities

No materials are required. The only utility requirement is electrical power. The electrical power needed for the light and the drive motor was estimated to be 3 KW of continuous power.

Additional process data may be obtained from Format A in Appendix III.

C2.7. Module Packing Process (MDLPKG)

C2.7.1. Design for High Volume Production

C2.7.1.1. Process Description

The function of this process is to pack two modules into a plastic case. When three plastic cases are fully loaded, they are placed onto a 2' x 2.5' x 4.5' wooden box to protect the modules from damage during shipment.

C2.7.1.2. Equipment Description

No special equipment is required for this process. Standard packing tools and a material handling system will be the only necessary equipment.

C2.7.2. Supporting Data for Format A

C2.7.2.1. Process Characteristics

The output of this process step is one module/min. The throughput rate is ten wooden boxes per hour. The average time spent at this station is 12 minutes since it takes six minutes to collect six modules and six minutes to pack them. The usage factor for this process is assumed to be 0.875.

C2.7.2.2. Equipment Cost Factor

The packing tool cost was estimated to be $5,000, and the material handling system also estimated to be $5,000.

C2.7.2.3. Floor Space and Labor

The required floor space is 128 sq. ft. This figure does not include storage space since the packed module will be transported by conveyor to the storage area immediately after it is packed. One packer is sufficient to pack the modules. Remaining labor requirements are identical to previous processes.

C2.7.2.4. Commodities and Utilities

The only direct materials required for this process step are packing materials such as plastic and wooden boxes.

Additional process data may be obtained from Format A in Appendix III.

C2.7.3. Price Computation

The price of a solar cell module was determined after the input data for each Format A was compiled. The cost computation proceeded in accordance with the procedures outlined in the process worksheets and company worksheets described in Reference (4). Additional expense item information which was not included in the cost account catalog in Reference (8) was found in currently available market price literature.

The overall cost for each module process was manually calculated and can be found in Table 29. The cost for each process was further subdivided into independent cost elements which include the cost in terms of 1980 cents per peak watt for equipment, floor space, labor, utilities and materials.

C3. Discussion of Results

The total added value for MODULCO including the encapsulation materials is 163.528 cents per peak watt in 1980 cents. This value is nearly an order of magnitude higher than the IPEG price goal of 21.42 cents per peak watt set forth in Reference (3). As shown in Table 29, the primary cause for the high module cost is the high module material cost, which accounts for 156.487 cents per peak watt, or 96 percent of the total cost for MODULCO.

Table 29. MODULCO Process Cost Summary (Plan A). Module is Based on Present Technology. Costs are in 1980 cents per peak watt.

PROCESS NUMBER	PROCESS REFERENT	EQUIPMENT	FLOOR SPACE	LABOR	MATERIAL & BY-PRODUCTS	UTILITIES	TOTAL
M-1	INTCON	0.165	0.518	0.336	119.490*	2.472	122.981*
M-2	MDLAYUP	0.113	0.158	0.329	25.634	0.006	26.240
M-3	DEGAS	0.125	0.053	0.438	0.0	0.094	0.710
M-4	ENCAP	0.319	0.102	0.116	0.0	0.532	1.069
M-5	FRMASEM	0.010	0.154	0.077	10.613	0.004	10.858
M-6	MDLTEST	0.104	0.022	0.265	0.0	0.004	0.395
M-7	PKGMDL	0.014	0.024	0.487	0.750	0.0	1.275
TOTAL		0.850	1.031	2.048	156.487*	3.112	163.528

*Highest Cost Elements

A detailed cost breakdown for the module material costs is presented in Table 30. The single highest material cost element is the flexible printed circuit sheet, which accounts for 119.490 cents per peak watt. The encapsulation material alone, which includes the glass, PVB, Mylar, aluminum frame, sealant, terminals, and packing materials, accounts for 36.997 cents per peak watt. This value is very high compared to the IPEG price goal of 3.78 cents per peak watt for module encapsulation material in Reference (3).

An interesting aspect, not to be overlooked, is the cost for the module assembly process alone, which is the difference between the total module cost and the sum of the flexible printed circuit sheet and the encapsulation material cost. The module assembly process cost is only 7.042 cents per peak watt. This value is less than one-half in the cost goal of 17.64 cents (adjusted) per peak watt presented in Reference (3) for the MODULCO module assembly process.

It can be concluded from the above analysis that the flexible printed circuit sheet interconnection scheme reduces the module assembly cost considerably; however, the current high cost of the flexible printed circuit sheet is unacceptable. It can also be concluded that the encapsulation material used in this program is too expensive and will not meet the 1986 IPEG price goals.

The module selling price (Plan A) which is based on present technology and work performed in this array automated assembly program, was found to be 158.6 cents per peak watt in 1975 cents. This price was obtained by summing the added values of each company as shown in Table 31. The wafer price for WAFERCO, 30.8 cents per peak watt, was obtained from the 1986 IPEG price goal in Reference (3). The CELLCO price of 27.719 cents per peak watt and the MODULCO price of 163.528 cents per peak watt, were both obtained earlier.

Table 30. Detailed Breakdown of MODULCO Module Material Costs (Plan A) in 1980 cents per peak watt.

Item	1980 Cents
Flexible PC Sheet	119.490 Cents
Lamination of Glass/PVB/Cell PVB/Mylar	25.634 "
Aluminum Frame, Sealant, Terminals	10.613 "
Packing Material	0.750 "
Total Cost	156.487 Cents

Table 31. MODULCO Module Selling Price (Plan A) in 1980 cents per peak watt.

	1980 Cents
WAFERCO	30.8 cents
CELLCO	27.710 "
MODULCO	163.528 "
MODULE SELLING PRICE	222.047/watt

The total module selling price of 222.047 cents per peak watt is more than three times the 1986 IPEG price goal, which is 70 cents per peak watt. The module encapsulation material cost discussed earlier, was found to be the major contributing factor to the high module selling price. Recommended encapsulation material modifications based on updated technology will be discussed in the following section.

C4. Recommended Direct Material Modifications

The recommended MODULCO direct material modifications are listed below:

(1) The flexible printed circuit sheet should be replaced with a stamped copper strip on Kapton to reduce the price from \$7.00/ft. to \$0.35/ft.

(2) Replacement of PVB sheet with EVA, to reduce the price from \$14.476/ft. to \$0.120/ft.

(3) The aluminum frame should be modified by changing its height and thickness to reduce the price from \$0.532/ft. to \$0.266/ft. Each of the above mentioned modifications is possible with updated technology.

C4.1. Discussion of Results

The cost for each process step in MODULCO was computed with the inclusion of the above recommended direct material modifications and is shown in Table 32. The total added value of MODULCO is 39.399 cents per peak watt in 1980 cents. This revised value is still much too high when compared to the IPEG price goal of 21.420 cents per peak watt in 1980 cents.

A detailed breakdown of the revised module material costs (Plan B) is presented in Table 33. It can be seen from this table that the module encapsulation materials alone account for 26.384 cents per peak watt which is well above the IPEG price goal of 3.78 cents per peak watt for

Table 32. MODULCO Process Cost Summary (Plan B). Module based on potential technology. Costs are in 1980 cents per peak watt.

PROCESS NUMBER	PROCESS REFERENT	EQUIPMENT	FLOOR SPACE	LABOR	MATERIAL & BY-PRODUCTS	UTILITIES	TOTAL
M-1	INTCON	0.165	0.518	0.336	5.975	2.472	9.466
M-2	MDLAYUP	0.113	0.158	0.329	19.712	0.006	20.318
M-3	DEGAS	0.125	0.053	0.438	0.0	0.094	0.710
M-4	ENCAP	0.318	0.102	0.116	0.0	0.532	1.069
M-5	FRMASEM	0.010	0.154	0.077	5.922	0.003	6.166
M-6	MDLTEST	0.104	0.022	0.265	0.0	0.004	0.395
M-7	PKGMDL	0.014	0.024	0.487	0.750	0.0	1.275
TOTAL		0.850	1.031	2.048	32.359	3.111	39.399

Table 33. Detailed Breakdown of MODULCO Module Material Costs (Plan B) in 1980 cents per peak watt.

Item	1980 Cents
Stamped Copper Strip	5.975 cents
Lamination of Glass/EVA/Cell/ EVA/Mylar	19.712 "
Aluminum Frame, Sealant, Terminals	5.922 "
Packing Material	0.750 "
Total Cost	32.359¢/watt

module encapsulation materials. The net module price without considering the encapsulation materials is 13.015 cents per peak watt which is below the IPEG price goal of 17.64 cents per peak watt.

The module selling price (Plan B) based on updated technology was found to be 97.918 cents per peak watt in 1980 cents. This price was obtained by summing the added values of each company as shown in Table 34.

The total module selling price of 97.918 cents per peak watt exceeds the 1986 IPEG price goal of 70 cents per peak watt in 1980 cents.

The major contributing factor in this cost overrun was the module encapsulation material cost. Since the encapsulation material task did not play a featured role in this program, it received only a cursory analysis. Consequently, it is highly recommended that future work be directed towards the development of alternative, low-cost encapsulation materials.

D. SAMICS PROCESS COST CONCLUSION

It can be concluded from a detailed SAMICS process cost analysis that the solar cell process costs and the module assembly costs (excluding the encapsulation material costs) are in line with the 1986 LSA cost goals.

A significant reduction in the overall solar cell fabrication cost can be achieved by reducing the metallization and antireflective coating costs. Candidates for reducing the cost of these two procedures are spray-on metallization and spray-on antireflective coating, respectively.

Table 34. MODULCO Module Selling Price (Plan B) in 1980 cents per peak watt.

	1980 Cents
WAFERCO	30.800 Cents
CELLCO	27.719 "
MODULCO	39.399 "
MODULE SELLING PRICE	97.918 Cents

The total module selling price of 97.918 cents per watt exceeds the 1986 LSA price goal of 70 cents per peak watt in 1980 cents. The major contributing factor for this cost over-run was the module encapsulation materials cost. Since the encapsulation material task did not play a featured role in this program, it received only a cursory analysis. Consequently, it is recommended that future work be directed toward the development of alternative, low-cost encapsulation materials.

V. CONCLUSIONS AND RECOMMENDATIONS

The following is a summary of the conclusions and recommendations presented throughout this report. Figure 55 is a flow chart of the entire process in its final form.

The *Wafer Surface Preparation Technique* without the H_2SO_4/H_2O_2 rinse and using an air dry was found effective, both technically and cost wise. RECOMMENDED

Spray-on Junction Formation is considered to be a major accomplishment of this contract and therefore, HIGHLY RECOMMENDED.

Aluminum Spray-on Metallization was found to have some problems associated with it but they were easily solved and the throughput/cost advantages, when automated, make this process RECOMMENDED.

Spray-on Antireflective Coating, like the Aluminum Spray-on metallization, needs automation. With it, the process, as modified, is RECOMMENDED.

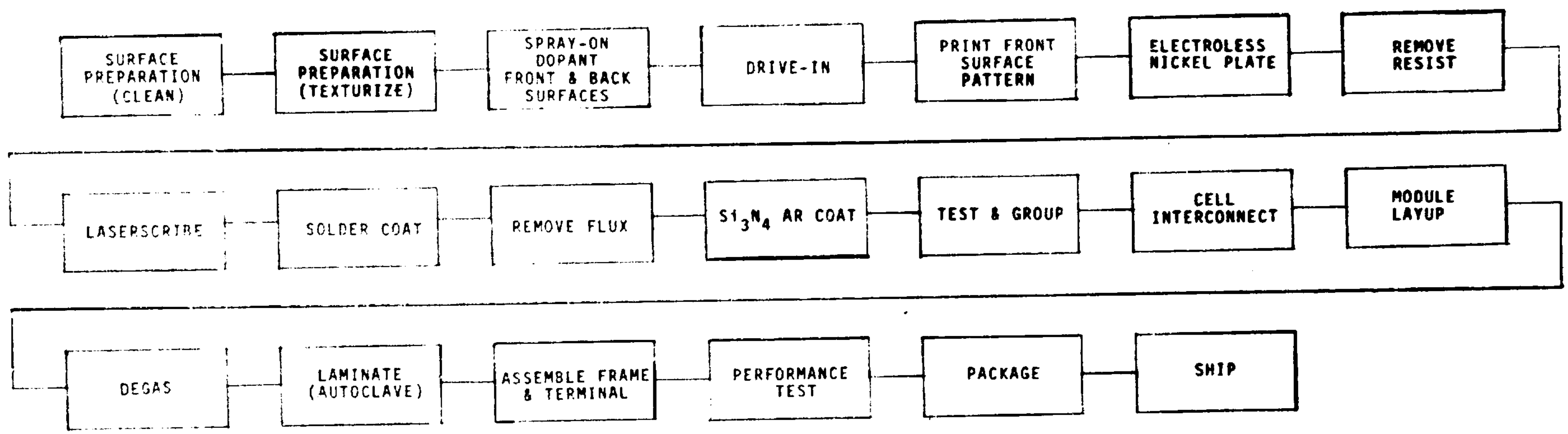
Conveyorized Dopant Diffusion was found to be UNACCEPTABLE.

Plasma Etching of Thick Film Resist was found to be too time consuming and costly. Therefore, it is UNACCEPTABLE.

Wafer Printing was found to be ACCEPTABLE.

Low Pressure Vapor Metal Depositions because of the inability to verify, can not be classed. NO RECOMMENDATIONS.

Wafer Plating In the present technology this was found to be effective. It represents the highest cost in wafer processing but it is RECOMMENDED.



PHOTOWATT INTERNATIONAL INC.

CONTRACT NO 954865

Figure 55

ENTIRE PROCESS FLOW CHART

(Final)

SIZE B

DO NOT SCALE DRAWING

Solder Coating and Flux Removal,
as optimized, were found ACCEPTABLE.

Silicon Nitride AR Coating
shows promise but, as it currently exists, it is UNACCEPTABLE.

Laser Trimming and Holing,
with the serial flow technique, is HIGHLY RECOMMENDED.

Laser Scanning Inspection
was found to need major modification. Since this modification does not appear to be forthcoming in the near future, the technique was found UNACCEPTABLE, BUT WITH POTENTIAL.

Cell Handling for Module Construction
as outlined in the body of this report (Section III, 0) is RECOMMENDED.

Module Fabrication Technique
was found to be too material intensive to be in line with 1986 goals and therefore, NEEDS FURTHER MODIFICATION.

Cell Test Data Acquisition
is RECOMMENDED.

Microwave Use In Fabrication
was found to show promise but, at the present level of accomplishments, is UNACCEPTABLE, BUT WITH POTENTIAL.

REFERENCES

1. G.T. Jones and S. Chitre, ERDA/JPL-954605-78/5, Development of Low-Cost, High Energy-Per-Unit-Area Solar Cell Modules, Final Report, JPL Contract 954605; LSSA Project, Automated Array Assembly Task, April 1978, Sensor Technology, Inc.

2. S.R. Chitre, The Conference Record of the Thirteenth IEEE Photovoltaic Specialists Conference - 1978, IEEE Press, p. 152 (1978).

3. R.G. Chamberlain and R.W. Aster, JPL-5101-33, "Interim Price Estimation Guidelines, A Precursor Adjunct to SAMIS III," Jet Propulsion Laboratory, Pasadena, CA, September 10, 1977.

4. R.G. Chamberlain, JPL-5101-15, "SAMICS (Solar Array Manufacturing Industry Costing Standards) Workbook," Jet Propulsion Laboratory, Pasadena, CA, September 1977.

5. R.G. Chamberlain, JPL-5101-44, "SAMICS Input Data Preparation (Solar Array Manufacturing Industry Costing Standards)," Jet Propulsion Laboratory, Pasadena, CA, September 30, 1977.

6. R.G. Chamberlain, JPL-5101-59, "SAMICS Usage Update No. 1," Jet Propulsion Laboratory, Pasadena, CA, February 1, 1978.

7. R.G. Chamberlain, JPL-5101-44A, "SAMICS Input Data Preparation (Solar Array Manufacturing Industry Costing Standards)," Jet Propulsion Laboratory, Pasadena, CA, March 1, 1979.

8. SAMICS Support Study, Final Report, Volume 1, "Cost Account Catalog," ERDA/JPL-954800-77/2.1, Theodore Barry & Associates, Management Consultants, Los Angeles, New York, Atlanta, Chicago, September 1977.

9. S.S. Rhee, G.T. Jones and K.L. Allison, DOE/JPL-954865-79/5, Phase 2 Array Automated Assembly Task, Annual Re-Report, JPL Contract 954865, LSA Project, Automated Assembly Task, January 1979 by Sensor Technology (unpublished).

APPENDIX I

INDUSTRY DESCRIPTION, FORMAT C

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT C

INDUSTRY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

C1 Industry Referent SAMICS - 86

C2 Description (Optional) 1986 STANDARD INDUSTRY

INDUSTRY OBJECTIVE

C3 Industry Result New Lower Cost Solar Modules

C4 Quantity Produced 500 Mega Watts/yr.

DESCRIPTION OF THE FINAL PRODUCT OF THE INDUSTRY

C5 Reference PKDMDL Name Packed Module

C6 Production is Measured in 5.56 Million Module/yr.

C7 Hardware Performance 90 peak watt/module (C4 per C6)

C8 Product Design Description (Optional) Module with 2' x 4' dimensions
Contain 119 equivalent full hexagonal cells of 90 mm
diameter, and produces 90 watts at 28°C, 100 mw/cm^2
insolation.

MAKERS OF THE FINAL PRODUCT OF THE INDUSTRY

C9 Company Reference MODULCO Market Share 40%

Company Reference ____ Market Share ____

Company Reference ____ Market Share ____

* The remaining companies are smaller than MODULCO, and are not listed.

Prepared by ____ Date ____

JPL 3039-S 11/77

APPENDIX II

COMPANY DESCRIPTION, FORMAT B
AND
PROCESS DESCRIPTION, FORMATS A
for
CELLCO FIRM

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT B

COMPANY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

B1 Company Referent CELLCO

B2 Description (Optional) Standard 1986, Wafer-To-Cell Company

B3 Product Produced PVCELL

B4			Process	CELTEST
B5	Intermediate Product	ARCC	Process	ARCT
	Intermediate Product	SDC	Process	SDFLW
	Intermediate Product	HEXC	Process	HEXLS
	Intermediate Product	CLNC	Process	RESREM
	Intermediate Product	NIPLC	Process	ELNIPL
	Intermediate Product	FSPPW	Process	FSPP
	Intermediate Product	JUNFW	Process	JUNCF
	Intermediate Product	SURPRW	Process	WFSURPR
	Intermediate Product		Process	
	Intermediate Product		Process	
	Intermediate Product		Process	

B6 Purchased Product PWAFER

B7 Supplier Company Reference WAFERCO Percent Supplied 100%

Supplier Company Reference Percent Supplied

Prepared by ______ Date ______

JPL 3038-S 11/77

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] SFSURPR

A2 [Descriptive Name] Wafer Surface Preparation

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] SURPRWF

A4 Descriptive Name [Product Name] Texturized and Surface Cleaned Wafer

A5 Unit Of Measure [Product Units] Wafer

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 99.5 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 96 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PROTNK	DRTUN	WFHDMC
A9a	Component [Descriptive Name] (Optional)	Process Tanks	Drier Tunnel	Wafer Handling
A10	Base Year For Equipment Prices [Price Year]	1978	1978	1978
A11	Purchase Price ($ Per Component) [Purchase Cost]	$120,000	$31,000	$20,000
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	$10,000	$3,000	$1,000
A14	[Removal and Installation Cost] ($/Component)	$4,000	$2,000	$500

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) WFSURPR

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	448	Sq.ft.	Factory Space (Type A)
B 3672 D	1	Prsn.a year	Chemical Operator II
B 3720 D	0.1	" " "	Inspector (Q.C.)
B 3736 D	0.05	Prsn.a year	Maintenance Mech II.
B 3688 D	0.05	Prsn.a year	Electronics Maint.
B 3256 B	0.02	" " "	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1001 D	0.09	Liter	Trichloroethylene
ET 1002 D	0.09	Liter	Methanol
E 1600 D	0.0882	Lbs.	Sodium Hydroxide
E 1416 D	0.0783	Cu.Ft.	Nitrogen Gas
C 1144	0.03531	Cu.Ft.	D.I.Water
C 2032 D	10	Cu.Ft.	Clean Compressed Air
C 1064 B	0.01	Cu.Ft.	Natural Gas
C 1032 B	0.289	Kw.Hr.	Electric Power
D 1048 B	1.676	Gal.	Polluted Water
D 1064 D	0.5	Wafer	Rejected Wafer

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
P WAFER	0.995	Wafer / Wafer	Wafer from Wafer Co.
		/	
		/	

Prepared by ______________________ Date ____________

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] JUNCF

A2 [Descriptive Name] Junction Formation by Spray-On Dopant Process Method

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] JUNFW

A4 Descriptive Name [Product Name] Wafer with junction formation and back surface field

A5 Unit Of Measure [Product Units] Wafer

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 19.9 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 107 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SPRMC	DRFURN	ETCHMC.
A9a	Component [Descriptive Name] (Optional)	Spray-on System	Dopant Drive-in	Excess Dopant
A10	Base Year For Equipment Prices [Price Year]	1978	1978	1978
A11	Purchase Price ($ Per Component) [Purchase Cost]	48200	25500	13500
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	5000	2500	1000
A14	[Removal and Installation Cost] ($/Component)	1000	500	200

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) JUNCF

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	220	Sq. ft.	Factory Space (Type A)
B 3704 D	0.25	Prsn-yr.	Operator
B 3720 D	0.02	" "	Inspector (Q.C.)
B 3736 D	0.02	" "	Mech.Maintenance
B 3256 B	0.005	" "	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1003 D	5×10^{-3}	l/min.	Phosphosilica Dopant
ET 1004 D	5×10^{-3}	l/min.	Borosilica Dopant
E 1416 D	8.83×10^{-3}	Cu.ft/min.	Nitrogen Gas
E 1448 D	8.83×10^{-3}	Cu.ft/min.	Oxigen Gas
E 1328 D	0.026	lbs./min.	Hydrofloric Acid
C 2032 D	4	Cu.ft./min.	Clean Compressed Air
C 1144 D	0.1334	Cu.ft./min.	D.I. water
C 1016 B	0.267	Cu.ft./min.	Domestic water
C 1032 B	0.575	Kw.hr/min.	Electricity
D 1048 B	2.992	Gal/min.	Poluted water
D 1064 D	0.1	Wafer/min.	Rejected water

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
SURPRWF	0.995	Wafer / Wafer	Surface Prepared Wafer

Prepared by ______ Date ______

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] FSPP

A2 [Descriptive Name] FRONT SURFACE PATTERN PRINTING

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] FSPPW

A4 Descriptive Name [Product Name] Front Surface Printed Wafer

A5 Unit Of Measure [Product Units] Wafer

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 49.8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 16 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	Printer	Drier	
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	1978	1978	
A11	Purchase Price ($ Per Component) [Purchase Cost]	20,000	30,000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	2,000	3,000	
A14	[Removal and Installation Cost] ($/Component)	200	1,500	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) FSPP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	360	Sq.ft.	Factory Space (Type A)
B 3704 D	0.25	Persn/yr	Operator
B 3736 D	0.05	" "	Maintenance Mech II.
B 3256 B	0.01	" "	Production Planner
B 3720 D	0.05	" "	Inspector

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1005 D	2×10^{-3}	gal/min.	Resist Tank
ET 1006 D	0.334×10^{-3}	gal/min.	Thinner
C 1032 B	0.305	Kw-hr/min.	Electric Power
D 1064 D	0.20	Wafer/min.	Rejected wafer

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
JUNFW	.996	Wafer/ Wafer	Wafer after diffusion
		/	
		/	

Prepared by ______________________ Date __________

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] ELNIPL

A2 [Descriptive Name] Electroless Nickel Plating.

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] NIPLC

A4 Descriptive Name [Product Name] Nickel Plated Cell

A5 Unit Of Measure [Product Units] Cell

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 29.82 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 20 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	NIPLTK	MTLHNDL	
A9a	Component [Descriptive Name] (Optional)	Nickel Plating System	Programable Material Handling System	
A10	Base Year For Equipment Prices [Price Year]	1978	1978	
A11	Purchase Price ($ Per Component) [Purchase Cost]	8232	10,000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	800	1,000	
A14	[Removal and Installation Cost] ($/Component)	900	1,000	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ELNIPL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	72	sq. ft.	Factory Space
B 3672 D	0.25	prsn.a yr.	Chemical Operator II
B 3720 D	0.05	" " "	Inspector (Q.C.)
B 3736 D	0.03	" " "	Maintenance Mech. II
B 3688 D	0.02	" " "	Electronic Maint.
B 3256 B	0.01	" " "	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E 1328 D	0.039	lbs.	Hydrofluoric Acid
ET 1007 D	0.015	liter	Gold Solution
ET 1008 D	0.150	liter	Nickel Solution
E 1416 D	0.706	cu.ft.	Nitrogen gas
C 1144 D	0.401	cu.ft.	D.I. water
C 1032 B	0.0087	Kw.Hr.	Electricity
D 1176 D	0.180	Cell	Rejected Cell

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
FSPPW	0.994	Cell/ Wafer	Front Surface Pat. Print Wafer

Prepared by ______ Date ______

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] RESREM

A2 [Descriptive Name] THICK RESIST REMOVAL BY WET CHEMICAL METHOD

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] CLNC

A4 Descriptive Name [Product Name] Cleaned Photovoltaic Cell

A5 Unit Of Measure [Product Units] Cell

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 17.5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	STRIPTANK	Hoist	
A9a	Component [Descriptive Name] (Optional)	Stripper Tank System	Lifter for basket transfer	
A10	Base Year For Equipment Prices [Price Year]	1978	1978	
A11	Purchase Price ($ Per Component) [Purchase Cost]	10,000	2,000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	1,000	500	
A14	[Removal and Installation Cost] ($/Component)	1,000	500	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) RESREM

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	64	Sq.ft.	Floor Space (Type A)
B 3672 D	0.25	Prsn.a yr.	Chemical Operator II
B 3736 D	0.05	" " "	Inspector (Q.C.)
B 3720 D	0.03	" " "	Mechanical Maintenance
B 3688 D	0.02	" " "	[illegible] Maintenanc
B 3256 B	0.01	" " "	[illegible] Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1009D	0.210	l/min.	Strip solution
ET 1002D	0.084	l/min.	Methanol
C 1144 D	0.4813	Cu.ft./min.	D.I.water
C 2032 D	0.0138	Cu.ft./min.	Clean Comp Air.
C 1032 B	0.2064	Kw.hr./min.	Electricity
D 1048 B	3.68	Gal/min.	Polluted water
D 1064 D	0.030	Cell/min.	Rejected cell.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
NIPLC	0.9995	Cell / Cell	Cleaned cell
		/	
		/	

Prepared by ______________________ Date ____________

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] HEXLS

A2 [Descriptive Name] Serial Flow Laserscribe System (Laser Trimming and Holing Operation)

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] HEXC

A4 Descriptive Name [Product Name] Hexagonal Cell

A5 Unit Of Measure [Product Units] Cells

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 119.4 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 0.317 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	Serial Flow		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	1986		
A11	Purchase Price ($ Per Component) [Purchase Cost]	520,000		
A12	Anticipated Useful Life (Years) [Useful Life]	6		
A13	[Salvage Value] ($ Per Component)	78,000		
A14	[Removal and Installation Cost] ($/Component)	15,600		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037 S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) HEXLS

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	250	sq.ft.	Factory Space
B 3704 D	1.0	Prsn.-yr.	Machine Operators
B 3720 D	0.1	Prsn.-yr.	Inspector (Q.C.)
B 3736 D	0.06	Prsn.-yr.	Maintenance
B 3688 D	0.04	Prsn.-yr.	Electronics Main.
B 3256 B	0.02	Prsn.-yr.	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E 1608 D	0.013	dollar/min.	Spare parts
C 1016 B	5.615	uA/min.	Cooling water
C 1032 B	1.112	Kw-hr/min.	Electric power
D 1176 D	0.60	Cell/min.	Rejected Cell

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
CLNC	0.995	Cells / Cells	Cleaned cells

Prepared by Date

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] SDFLOW

A2 [Descriptive Name] SOLDER COATING AND FLUX REMOVAL

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] SDC

A4 Descriptive Name [Product Name] Solder Coated Cell

A5 Unit Of Measure [Product Units] Cell

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 59.88 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 13.333 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SDMC	FLCLMC	MATHNOL
A9a	Component [Descriptive Name] (Optional)	SOLDER Coating Machine	FLUX Cleaning Machine	MATERIAL Handling Machine
A10	Base Year For Equipment Prices [Price Year]	9,000	11,500	5,000
A11	Purchase Price ($ Per Component) [Purchase Cost]	1978	1978	1978
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	1,800	2,000	1,000
A14	[Removal and Installation Cost] ($/Component)	500	300	500

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) SD FLOW

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	80	Sq.Ft.	Factory Space (Type A)
B 3672 D	0.25	Prsn.a yr.	Chemical Operator II
B 3720 D	0.05	Prsn.a Yr.	Inspector
B 3736 D	0.03	" " "	Mechanical Maintenance
B 3688 D	0.02	" " "	Electrical Maintenance
B 3256 D	0.01	" " "	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1010 D	1.5×10^{-3}	Gal/min.	Solder Flux
ET 1011 D	0.090	lbs/min.	60/40 Solder
C 1144 D	1.069	Cu.ft.	D.I. water
C 1032 B	0.2583	Kw.hr/min.	Electricity
D1048 B	8.0	Gal/min.	Polluted Water
D 1176 D	0.12	Cell/min.	Rejected Cell

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
HEXC	0.998	Cell / Cell	Hexagonal Scribed Cell
		/	
		/	

Prepared by ____________________ Date ____________

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] ARCT

A2 [Descriptive Name] Silicon Nitride Anti-Reflection Coating

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] ARCC

A4 Descriptive Name [Product Name] AR COATED CELLS

A5 Unit Of Measure [Product Units]

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4.98 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .20 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LFES		
A9a	Component [Descriptive Name] (Optional)	LFE 8000		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	74,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	10,000		
A14	[Removal and Installation Cost] ($/Component)	5,000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ARCT

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	40	Sq.ft.	Factory Space (Type A)
B 3704 D	.1	Prsn.yr.	Operator
B 3736 D	.01	Prsn.yr.	Maintenance Mech II
B 3256 B	.005	Prsn.yr.	Production Planner
B 3720 D	.005	Prsn.yr.	Inspector

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1037 B	.1715	Kw.hrs./min.	Electric Power
ET 1012 D	.069	Cu.ft/min.	1.5% silane/argon
D 1174 D	0.03	Cell/min.	Rejected cell

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
SDC	0.996	Cell / Cell	Solder dipped cell

Prepared by ______ Date ______

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] CELTEST

A2 [Descriptive Name] Cell Electric Performance Test and Grouping Process

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TESTC

A4 Descriptive Name [Product Name] Tested and Grouped Cell

A5 Unit Of Measure [Product Units] Cell

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 59.64 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 0.33 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	CTG		
A9a	Component [Descriptive Name] (Optional)	Cell tester and grouping machine		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	47,500		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	5,000		
A14	[Removal and Installation Cost] ($/Component)	2,000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037 S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CELTEST

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	70	Sq.ft.	Factory Space (Type A)
B 3768 D	0.25	Prsn.yr.	Tester
B 3720 D	0.05	Prsn.yr.	Inspector
B 3736 D	0.03	Prsn.yr.	Maintenance Mech. II.
B 3688 D	0.02	Prsn.yr.	Electronic Maintenance
B 3256 B	0.01	Prsn.yr.	Production Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1032 B	0.1375	Kw.hr./min.	Electricity
D 1174 D	0.36	Cell/min.	Rejected cell

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
ARCC	0.994	Cell / Cell	A.R.Coated Cell

Prepared by ______________________ Date ____________

REVERSE SIDE JPL 3037 S R 7/78

APPENDIX III

COMPANY DESCRIPTION, FORMAT B

AND

PROCESS DESCRIPTION, FORMATS A

for

MODULCO FIRM

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT B

COMPANY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

B1 Company Referent MODULCO

B2 Description (Optional) Module Fabrication From Photovoltaic Cells

B3 Product Produced PKD MDL

B4		Process	MDLPKG
B5	Intermediate Product TESTEDMDL	Process	MDLTEST
	Intermediate Product PVMDL	Process	FRMASEM
	Intermediate Product ENCAPMDL	Process	ENCAP
	Intermediate Product VACBAGD	Process	DEGAS
	Intermediate Product MDLAYER	Process	MDLAYUP
	Intermediate Product MDSTRING	Process	INCON
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	

B6 Purchased Product PVCELL

B7	Supplier Company Reference CELLCO	Percent Supplied	100%
	Supplier Company Reference	Percent Supplied	

Prepared by ____________________ Date ____________

JPL 3038-5 11/77

PAGE 244 INTENTIONALLY BLANK

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] INTCON

A2 [Descriptive Name] Cell Interconnection Through Flexible Circuit Sheet

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] CELSTRNG

A4 Descriptive Name [Product Name] Interconnected cell strings for module.

A5 Unit Of Measure [Product Units] String

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.985 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 23 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	All machine	Conveyor	Fixture
A9a	Component [Descriptive Name] (Optional)	Two Loader Cell depositor Sold M/C	Conv. # 1 Conv. # 2 Conv. # 3	Carrier Fixture
A10	Base Year For Equipment Prices [Price Year]	1978	1978	1978
A11	Purchase Price ($ Per Component) [Purchase Cost]	95,000	18,000	3,400
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	20,000	4,000	400
A14	[Removal and Installation Cost] ($/Component)	5,000	2,000	--

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) INTCON

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	1400	sq.ft.	Floor space
B 3704 D	0.5	Prsn./yr.	Electronics Technician
B 3736 D	0.1	Prsn./yr.	Maintenance Mech II.
B 3720 D	0.1	" "	Inspector (Q.C.)
B 3256 B	0.02	" "	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1021 D	1	Sheet	Flexible Circuit Sheet
C 2032 D	108	cu.ft.	Compressed air
C 1032 B	0.455	Kw.hr./min.	Electricity

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
PVCELL	0.00828	String / Cell	Photovoltaic Cell.

Prepared by ______ Date ______

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] MDLAYUP

A2 [Descriptive Name] Module Elements Lay-up.

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] MDLAYER

A4 Descriptive Name [Product Name] Module Element Layers in proper order.

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) .995 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 15 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LOADER	CONVEYOR	FIXTURE
A9a	Component [Descriptive Name] (Optional)	Six loaders		120 fixtures
A10	Base Year For Equipment Prices [Price Year]	1978	1978	1978
A11	Purchase Price ($ Per Component) [Purchase Cost]	55,000	10,000	12,000
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	5
A13	[Salvage Value] ($ Per Component)	10,000	2,000	1,200
A14	[Removal and Installation Cost] ($/Component)	4,000	2,000	--

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) MDLAYUP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	840	Sq.ft.	Floor space
B 3704 D	0.5	Prsn/yr.	Electronic Technician
B 3436 D	0.1	Prsn/yr.	Maintenance
B 3720 D	0.1	Prsn/yr.	Inspector (Q.C.)
B 3256 B	0.02	" "	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1021 D	8	Sq.ft./min.	Sunadex Glass 0.125 Tempered
ET 1023 D	16	Sq.ft./min.	PVB 0.015"
ET 1024 D	8	Sq.ft./min.	Mylar 0.005 in.
C 1032 B	0.063	Kw.hr/min.	Electricity.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
CELSTRNG	0.995	~~Module~~ String	Cell String

Prepared by ____________ Date ____________

REVERSE SIDE JPL 3037 S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] DEGAS

A2 [Descriptive Name] Degassing Procedure of Module Layer

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] VACBAGED

A4 Descriptive Name [Product Name] Vacuum Bagged Module Layer

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.985 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 30 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	Degas	Conv.	
A9a	Component [Descriptive Name] (Optional)	Degassing equip. 5 unit	Conveyor for both stations	
A10	Base Year For Equipment Prices [Price Year]	1978	1978	
A11	Purchase Price ($ Per Component) [Purchase Cost]	72,000	10,000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	15,000	2,000	
A14	[Removal and Installation Cost] ($/Component)	10,000	1,000	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) DEGAS

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	280	sq.ft.	Floor space
B 3080	1	Prsn. yr.	Module Assembler
B 3676 D	0.1	Prsn.yr.	Maintenance Mech. II
B 3720 D	0.1	Prsn.yr.	Inspector (Q.C.)
B 3256 B	0.02	Prsn.yr.	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1032 B	0.992	Kw.hr/min.	Electricity

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
MDLAYER	0.985	Module / Module	Module Layer

Prepared by ______ Date ______

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] ENCAP

A2 [Descriptive Name] Module Lamination Process Through Autoclave

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] ENCAPMDL

A4 Descriptive Name [Product Name] Encapsulated Module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.995 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 60 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	AUTOCLAVE		
A9a	Component [Descriptive Name] (Optional)	Ten autoclave system		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	210,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	20,000		
A14	[Removal and Installation Cost] ($/Component)	10,000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ENCAP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	560	sq.ft.	Floor space
B 3704 D	1	Prsn.yr.	Module Assembler
B 3736 D	0.1	Prsn.yr.	Maintenance, Mech. II
B 3720 D	0.1	" "	Inspector (Q.C.)
B 3256 B	0.02	" "	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1032 B	2	Kw.hr./min.	Electricity
C 2032 D	16	Cu.ft/min.	Compressed air

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
VACBAGMD	0.995	MDL / MDL	Vacuum Bagged module
		/	
		/	

Prepared by ______________________ Date ____________

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] FRMASSEM

A2 [Descriptive Name] Frame and Terminal Assembly

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] ASMMDL

A4 Descriptive Name [Product Name] Assembled Module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.999 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 6 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	Tools	Fixture	
A9a	Component [Descriptive Name] (Optional)	Rivet gun drill SD.gun etc.	Working table and asembly fixture.	
A10	Base Year For Equipment Prices [Price Year]	$3,000	$4,000	
A11	Purchase Price ($ Per Component) [Purchase Cost]	1978	1978	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	500	500	
A14	[Removal and Installation Cost] ($/Component)	--	--	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ~~FRMASSEM.~~

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
~~A 2064 D~~	~~860~~	~~Sq.ft.~~	~~Floor space~~
~~B 3704 D~~	~~6~~	~~Prsn.yr.~~	~~Module assembler~~
~~B 3736 D~~	~~0.1~~	~~Prsn.yr.~~	~~Maintenance Mech II.~~
B 3720 D	0.1	Prsn. yr.	Inspector (Q.C.)
B 3256 B	0.02	Prsn.yr.	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1032 B	0.033	Kw.hr./min.	Electricity
~~ET 1027 D~~	~~12~~	~~Ft./min.~~	~~Aluminum Frame~~
ET 1028 D	0.072	1/min.	Silicon sealant
~~ET 1029 D~~	~~1~~	~~set/min.~~	~~Terminal~~

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
ENCAPMDL	0.999	Mdl. / Mdl.	Encapsulated Modules
		/	
		/	

Prepared by ______________________ Date ____________

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] MCLTEST

A2 [Descriptive Name] Module Performance Test

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TESTMDL

A4 Descriptive Name [Product Name] Tested Module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.9925 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 6 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	MDTESTER		
A9a	Component [Descriptive Name] (Optional)	MDLPerformance testing m/c		
A10	Base Year For Equipment Prices [Price Year]	1978		
A11	Purchase Price ($ Per Component) [Purchase Cost]	75,000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	15,000		
A14	[Removal and Installation Cost] ($/Component)	5,000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) MDLTEST

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	128	sq.ft.	Floor space
B 3768 D	0.5	Prsn.yr.	Tester Elec. Comp.
B 3736 D	0.1	Prsn.yr.	Maintenance Mech. II.
B 3720 D	0.1	Prsn.yr.	Inspector, Q.C.
B 3256 B	0.02	Prsn.yr.	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C 1032 B	0.05	kw.hr/min.	Electricity

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
TESTMDL.	0.9925	Mdl. / Mdl.	Performance tested module

Prepared by ______ Date ______

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] MDLPKG

A2 [Descriptive Name] MODULE PACKING

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PKDMDL

A4 Descriptive Name [Product Name] Packed Module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.9999 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 12 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.875 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PKNGTOOL	MOVEQUIP	
A9a	Component [Descriptive Name] (Optional)	Packing tools	Module handling equip.	
A10	Base Year For Equipment Prices [Price Year]	5,000	5,000	
A11	Purchase Price ($ Per Component) [Purchase Cost]	1978	1978	
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	
A13	[Salvage Value] ($ Per Component)	500	500	
A14	[Removal and Installation Cost] ($/Component)	--	--	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PDKMDL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	128	Sq.ft.	Floor space
B 3640 D	1	Prsn.yr.	Packager hand
B 3736 D	0.1	Prsn.yr.	Maintenance Mech II.
B 3720 D	0.1	Prsn.yr.	Inspector Q.C.
B 3256 B	0.2	Prsn.yr.	Prod. Planner

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET 1025 D	0.5	Box/min.	Packing box
ET 1026 D	0.1667	Case/min.	Wooden case

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
TESTMDL	0.9999	Mdl. / Mdl.	Tested Module

Prepared by ______ Date ______

REVERSE SIDE JPL 3037-S R 7/78

APPENDIX IV

TEMPORARY CATALOG FOR EXPENSE ITEMS

LIST OF TEMPORARY CATALOG ITEMS

NUMBER	ITEM DESCRIPTION	UNIT	PRICE	IC	YEAR
ET 1001D	Trichloroethylene	Liter	2.03	C	77
ET 1002D	Methanol	Liter	1.13	C	77
ET 1003D	Phosphosilica dopant	Liter/min	17.545	C	86
ET 1004D	Borosilica dopant	Liter/min	17.545	C	86
ET 1005D	Resist ink	Gal/min	32.00	C	77
ET 1006D	Thinner	Gal/min	40.00	C	77
ET 1007D	Gold solution	Liter	13.40	C	78
ET 1008D	Nickel solution	Liter	1.210	C	78
ET 1009D	Strip solution	Liter/min	1.178	C	77
ET 1010D	Solder flux	Gal/min	16.50	C	77
ET 1011D	60/40 solder	Lbs/min	6.04	D	77
ET 1012D	1.5% silane/argon	cu.ft/min	.648	C	86
ET 1021D	Flexible circuit sheet,2'x4'	Sheet	40	C	78
ET 1022D	Sunadex glass; 0.125", tempered	Sq. ft	0.68	C	78
ET 1023D	Polyvinyl butyral; 15 mils	Sq. ft	0.17	C	78
ET 1024D	Mylar, 0.005, surface treated	Sq. ft	0.08	C	78
ET 1025D	Carton box, two MDL pack.	Box	0.50	D	78
ET 1026D	Wooden case for 6 modules	Case	0.80	D	78
ET 1027D	Aluminum frame A(3",1/8"THK)	Ft.	0.38	D	78
ET 1028D	Silicone rubber sealant	Liter	9.4	D	78
ET 1029D	Terminal	Set	.15	D	78
ET 1030D	Aluminum frame B(2", 3/12"THK)	Ft.	.19	D	78
ET 1031D	EVA "clear" (20 mil)	Sq. ft	0.043	D	78
ET 1032D	EVA white sheet (12 mil)	Sq. ft.	0.043	D	78
ET 1033D	Stamped copper strip	Sq. ft	0.25	D	78
C2032D	Compressed air	cu. ft	0.00634	E	77

PAGE 262 INTENTIONALLY

APPENDIX V

ENGINEERING SPECIFICATIONS

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

SURFACE PREPARATION (CLEAN)

1.0 OBJECT

1.1 The purpose of this specification is to outline the method by which contamination is removed from the surface of raw wafers.

2.0 MATERIAL

2.1 Wafers from stock.

3.0 EQUIPMENT

3.1 Tanks (2), stainless steel, approximately 18" x 11' x 17".

3.2 Cassettes, 25 wafer capacity, teflon 3.3 cassettes carrier basket, teflon.

3.3 Cassette carrier basket, teflon.

4.0 SUPPLIES

4.1 Methanol, electronic grade

4.2 Trichlorethylene, electronic grade

4.3 Gloves, solvent resistant

4.4 Facemask

5.0 PREPARATION

5.1 Load wafers into cassettes

5.2 Fill first tank with trichlorethylene to sufficient volume to cover cassettes in carrier basket.

5.3 Fill second tank with methanol to same volume.

5.4 Load cassettes, four at a time, into carrier basket.

6.0 PROCEDURE

6.1 Immerse loaded carrier into first tank and allow to remain for five minutes.

6.2 Transfer to second tank and allow to remain for five minutes.

6.3 Remove from second tank and transfer to texturizing process.

7.0 MAINTENANCE

7.1 Change contents of tank every eight hours.

8.0 SAFETY

8.1 Refer to MCA specifications for toxicity values of methanol and trichlorethylene.

Prepared by: [illegible] Date: [illegible]

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

SURFACE PREPARATION (TEXTURIZE)

1.0 OBJECT

1.1 This specification outlines the manner in which the texturizing operation is performed.

2.0 MATERIAL

2.1 Wafers from the contamination removal process still loaded into cassettes and cassette carriers.

3.0 EQUIPMENT

3.1 Etching tank, stainless steel approximately 10" x 14" x 18" equipped with a Deltasonic Model MG600 ultrasonic generator or equivalent and a Deltasonic Model UTCM-98P heater or equivalent.

3.2 Nitrogen bubbler, per attached drawing.

3.3 Exhaust system over the etching tank.

3.4 A four-stage cascade rinse system, the first used tank of which is equipped with a Deltrasonic Model MG600 ultrasonic generator. Approximately 10" x 14" x 11.5" per tank.

3.5 Rinser/spin dryer, Fluoroware Model K100 or equivalent.

4.0 SUPPLIES

4.1 Sodium hydroxide, electronic grade

4.2 Deionized water

4.3 Hot deionized water

4.4 Nitrogen, industrial dry grade

4.5 Gloves, base resistant

4.6 Facemask

4.7 Safety apron

5.0 PREPARATION

5.1 Adjust cascade input (tank 4) DI water temperature to 80°C ± 2°C and the flow rate to 2 gal/min.

5.2 Measure 20 liters of ambient temperature DI water into etch tank.

5.3 Dissolve 2.2 kilograms of sodium hydroxide in the etch tank.

5.4 Adjust temperature of the etch tank solution to 85°C ± 5°C.

PAGE 268 INTENTIONALLY BLANK

5.0 (Continuation)

5.5 Turn on ultrasonic generators, exhaust system and nitrogen.

5.6 Adjust nitrogen flow to approximately 10L/min.

5.7 Adjust rinser/dryer for one minute rinse and four minute drying.

6.0 PROCEDURE

6.1 Immerse a carrier of wafer loaded cassettes into the heated etch solution for five minutes.

6.2 Transfer the carrier load to the first cascade rinse tank and allow to remain for five minutes.

6.3 Stage through the cascade at five minute intervals.

6.4 When the cascade rinse treatment has been completed, remove the cassettes from the carrier and place into the rinser/dryer.

6.5 After the cycle has been completed, pass the cassettes to the "Spray-on Dopant" process.

7.0 MAINTENANCE

7.1 Add one liter of deionized water every half hour to etch tank.

7.2 Change the sodium hydroxide solution every four hours of use.

8.0 SAFETY

8.1 Refer to the MCA specifications for safe limits of toxicity on aqueous solutions of sodium hydroxide.

8.2 All operations are to be performed with gloves and and facemask in place.

8.3 In the vicinity of the sodium hydroxide tank a safety apron must be worn.

Prepared by: ______________ Date: ______________

PX-01B

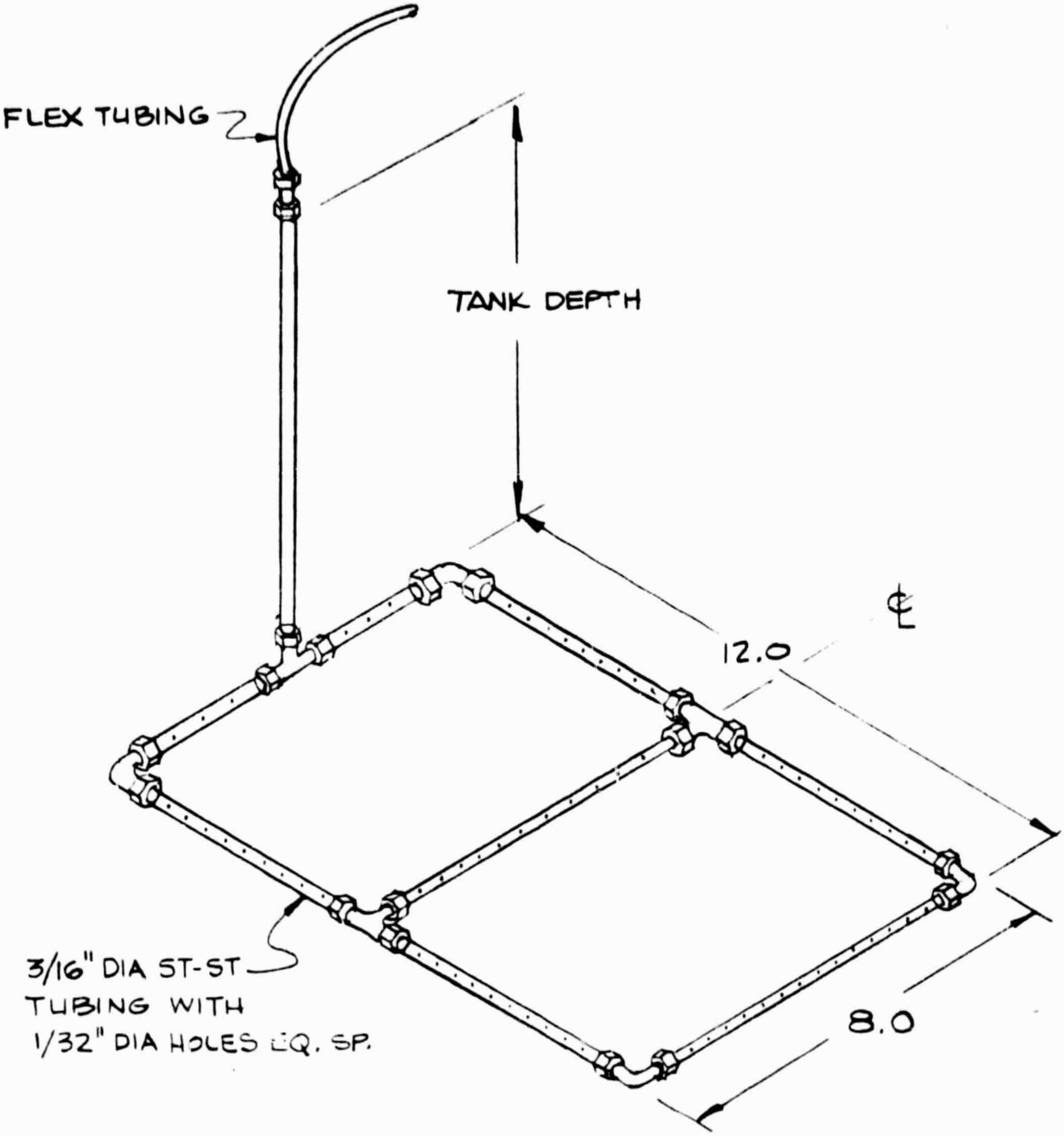


Figure 56. Nitrogen Bubbler

PHOTOWATT INTERNATIONAL INC. 2414 W. 14TH ST. TEMPE, AZ 85281	NITROGEN BUBBLER			
DRAWN RC	SIZE A	FSCM NO.	DWG. NO. 10.10.2452	REV. –
ISSUED 1-30-81	SCALE NONE		SHEET 1 OF 1	

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

SPRAY-ON DOPANT FRONT & BACK SURFACES

1.0 Object

1.1 This specification outlines the technique whereby one surface is coated with a dopant. This is the front surface. Included in this series of Specifications is one that is not shown on the flow chart, "Spray-on Aluminum Back Surface." It, in combination with this specification, would serve to cover the entire "Spray-on Front and Back Surfaces."

2.0 Material

2.1 Wafers from "Surface Preparation Texturize."

2.2 Water base N^+ dopant (N-250, Emulsitone Co., Whippany, NJ). Phosphorous concentration of 1×10^{18} atoms/cm^3.

3.0 Equipment

3.1 Spray-on dopant machine, Model SC-100. (Advanced Concepts Div., Huestis Machine Corp., Bristol, RI).

3.2 Pallets for holding wafers.

3.3 Filter UL Class 2-347N, (23½" x 23½" x 1 7/8").

3.4 Exhaust system capable of 1000 CFM.

3.5 Graduated cylinder, 10 ml.

3.6 Stopwatch or timer.

3.7 Small ultrasonic generator and tank.

4.0 Supplies

4.1 DI water.

4.2 Nitrogen gas at a pressure in excess of 60 psig.

4.3 Insulated gloves.

4.4 Acetone, industrial grade.

5.0 Preparation

5.1 Pour dopant (2.2) into the cannister feeding gun 1.

5.2 Turn on IR oven (SW2).
5.2.1 Set temperature (CV-3) to 350°F.
5.2.2 Allow the temperature to stabilize for at least 15 minutes.

5.3 Verify the input nitrogen pressure is 60 psig.

5.4 Actuate the nitrogen valve (V3B) and adjust to 9 psig on G3B.

5.5 Turn on the conveyor switch, SW1.

5.6 Adjust CV1 to produce 24 ipm speed in the conveyor belt.

5.7 When speed is verified, turn off the conveyor switch SW1.

5.8 Turn on SW3 and adjust reciprocator.+++

5.9 Set G1A to 90 inches of water with V1A.

5.10 Insert the spray nozzle and attach the wing nut to gun 1. The wings of the wing nut should be parallel to the direction of motion of the gun.

5.11 Turn SW4 to the spray position.

5.12 Verify, using the graduated cylinder and stopwatch/timer, that the flow rate is 7 ml per minute.

5.13 Set G2A to 15 psig using V2A.

5.14 Examine the pattern produced by gun 1.

5.14.1 There should be no variation in the flow rate from the nozzle. Such variation indicates an unclean spray nozzle (see 7.5).

5.14.2 The pattern should have no more than one inch width at the conveyor level. This is adjusted by the tightness of the wing nut.

5.15 Turn on switches SW1 (conveyor) and SW3 (reciprocator).

6.0 Procedure

6.1 Place the loaded pallets onto the conveyor in such manner that the hooks engage the chain.

6.2 After the pallets have exited the IR oven, remove them from the conveyor using the insulated gloves.

6.3 For non-continuous operation, at the end of the pallet load shut down the machine.

6.3.1 Change SW4 to flush and adjust V3A to 15 psig on G3A.

6.3.2 Turn off SW3, V1A, V2A.

6.3.3 After two minutes, turn off V3A.

6.3.4 Turn off SW1, SW2.

7.0 Maintenance

7.1 Check all solvents and dopants prior to use. If they appear discolored or cloudy they should be discarded, the containers cleaned and new contents inserted.

7.2 Change filters in the air dry section monthly.

7.3 Change the filter under the conveyor twice monthly.

7.4 Empty the excess dopant container as required, usually once daily.

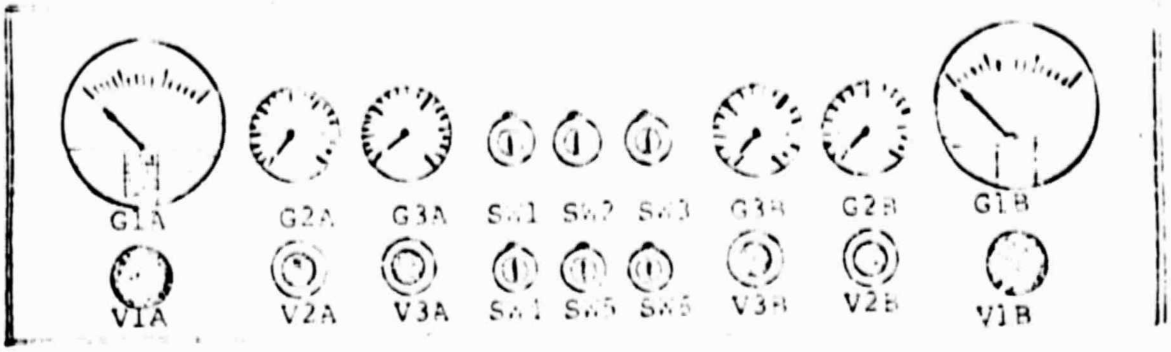
7.5 The nozzle cleaning is accomplished by placing it in acetone in an ultrasonic tank.

8.0 <u>Safety</u>

8.1 The outside of the IR oven is hot.

8.2 See the MCA Specifications for safe handling of acetone (dimethylketone).

Prepared by: [illegible] Date: [illegible]/81



GAUGES

G1A: Pot pressure gauge (in H_2O) for coating material 1, 0-150 psig
G1B: Pot pressure gauge (in H_2O) for coating material II, 0-150 psig
G2A: Atomization pressure for spray gun I, 0-60 psig
G2B: Atomization pressure for spray gun II, 0-60 psig
G3A: Solvent Pot Pressure, 0-30 psi
G3B: Lower Pressure Control Manifold, 0-15 psig

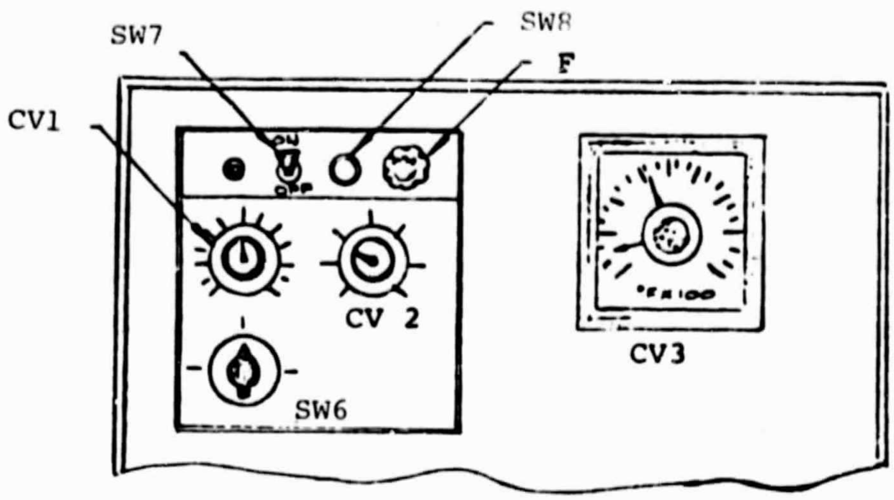
CONTROL KNOBS

V1A: Control valve for Pot Pressure for Material I
V1B: Control valve for Pot Pressure for Material II
V2A: Atomization Pressure for Gun I
V2B: Atomization Pressure for Gun II
V3A: Solvent Pot Pressure
V3B: Lower Pressure Control Manifold

SWITCHES

SW1: Conveyor on-off switch
SW2: I.R. oven on-off switch
SW3: Nozzle reciprocator on-off switch
SW4: Selector switch for spray and flush for Gun I
SW5: Selector switch for Gun I and Gun II
SW6: Selector switch for spray and flush for Gun II

Figure 57. Description of Control Panel #1



CV1: Conveyor Speed Control 0 - 100 ipm

CV2: Reciprocator Speed Control 100 - 200

CV3: Temperature Control 0 - 800^{0}F

SW6: Selector Switch for Conveyor Direction

SW7: On/Off Master Switch

SW8: Reset Button

F : Fuse

Figure 58. Illustration of Control Panel # 2

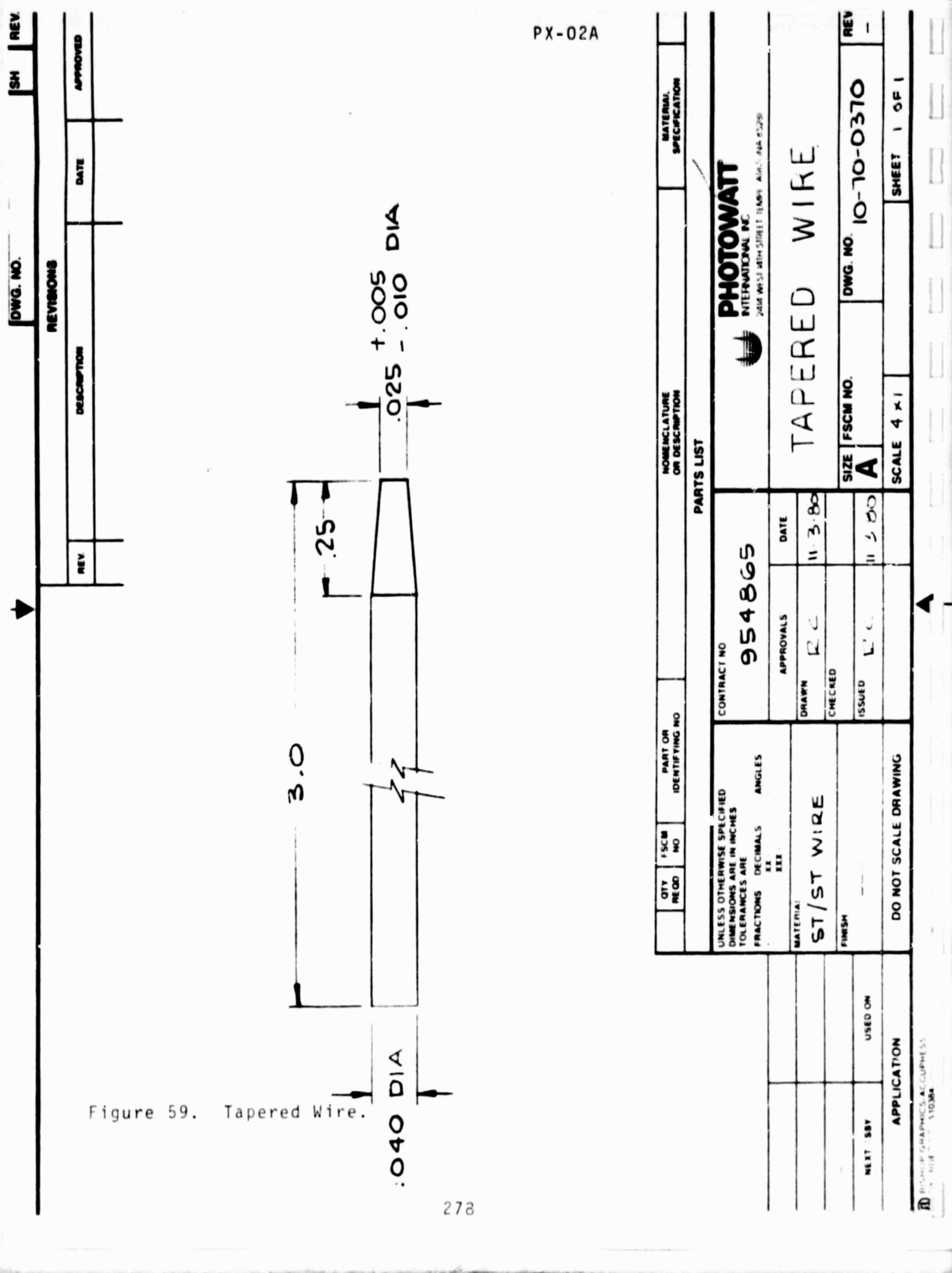


Figure 59. Tapered Wire.

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

DEPOSIT ALUMINUM ON BACK SURFACE

1.0 Object

1.1 To deposit aluminum on the back surface of wafers.

1.2 To drive the solvents from the deposited aluminum.

2.0 Material

2.1 Solvent solution, 2-butoxyethanol, Mallinckrodt Chemicals No. 2138 or equivalent.

2.2 Acetone, reagent grade.

2.3 Wafers, prepared for aluminum BSF.

3.0 Equipment

3.1 Spray-on aluminum slurry and dopant machine with I.R. oven. Advanced Concepts Model SC-100 (as modified on Serial Numbers 79-337 and 78-281).

3.2 Ultrasonic cleaner, any commercial model.

4.0 Supplies

4.1 Pallets designed for the wafers being used (Figure).

4.2 Gloves, insulated.

4.3 Filter UL Class 2 - 347N, size 23½" x 23½" x 1 7/8".

4.4 Exhaust system capable of 1000 CFM.

4.5 Clean, dry air at a pressure of 85 to 100 psig.

4.6 Container for storage of wing nut and nozzle prior to cleaning - suggest 400 ml glass beaker.

4.7 400 ml glass beaker for use in ultrasonic tank.

4.8 Tapered steel wire per Figure .

4.9 Graduated cylinder, 10 ml capacity.

4.10 Stopwatch or clock with sweep second hand.

4.11 Filter cartridge, commercial paint type.

5.0 Preparation

5.1 Pour the aluminum slurry into the pump reservoir canister through a filter cartridge.

5.2 Turn-on the infrared oven.

5.2.1 Set temperature to 350^{o}F (117^{o}C). (CV3)

5.2.2 Allow temperature to stabilize for 15 minutes.

5.3 Set or check the primary air valve pressure to 80 psig.

5.4 Open the primary air valve.

5.5 Set the manifold control valve (V1) to produce 10 psig on G1. CAUTION: Do not exceed 11 psig.

5.6 Turn on conveyor switch (SW6).

5.7 Set conveyor speed to 15 inches/minute (CV-1).

5.8 Turn off conveyor (SW 6).

5.9 Set the nozzle reciprocator speed to 60 cycles/minute (CV 2).

5.10 Verify that the pressure of the coating aluminum material gauge (G2) registers 9 psig. If not, adjust by balancing the pressure reduction, bypass and back pressure valves (located on the back of the machine - blue handles).

5.10.1 The bypass valve is located directly above the pump reservoir. It serves to minimize aluminum settlement in the lines. It should be completely open.

5.10.2 The pressure reduction valve is located about three feet high and to the right of the pump reservoir. When pressure is low it is open, but under normal conditions it should be closed. Its function is to reduce the aluminum slurry pressure/flow rate to the nozzle.

5.10.3 The back pressure valve is located about five feet above the floor and to the right of the pump reservoir. If closed, it increases the aluminum slurry pressure/flow rate to the spray nozzle.

5.11 Insert the spray nozzle.

5.12 Hold nozzle in with the wing nut.

5.12.1 Assure that the wing nut wings are aligned with the direction of motion of the spray nozzle.

5.13 Turn the process selector switch to position 7.

5.14 Turn the spray gun selector switch (SW4) to the spray position.

C-4

5.15 Verify that the aluminum slurry flow rate is 7 cc/minute.

5.15.1 Collect the flow for one minute in a 10 cc graduated cylinder.

5.16 Set the atomization spray gun control valve (V3) to 18 psig on G3.

5.17 Turn on atomization (SW 5).

5.18 Adjust the nozzle using nut to produce a pattern no wider than one inch (measured in the plane of flow of the conveyor).

5.19 Turn off the atomization switch (SW 5).

5.20 Turn the process switch to position 8.

5.21 Load the required wafers onto pallets.

6.0 <u>Procedure</u>

6.1 Turn on conveyor (SW 6).

6.2 Turn on nozzle reciprocator (SW2).

6.3 Verify the atomization gun pressure is 18 psig on G3.

6.4 Verify the pressure of G2 is 9 psig.

6.4.1 If 6.3 or 6.4 do not conform, refer to Section 5.0 for proper adjustment.

6.5 Place process selector switch in position 7.

6.6 Place pallet loaded with wafers from 5.21 on conveyor.

6.7 As the pallets are taken into the machine continue to load additional pallets until supply is exhausted.

6.8 As pallets exit the infrared oven, remove them from the conveyor.

6.8.1 The pallets are hot at this point. Use the thermally insulated gloves.

6.9 When all pallets have passed through the spray booth, turn process selector switch to position 9. Allow the slurry in the lines to empty into the alternative collection vessel.

6.10 Turn process selector switch to position 1.

6.11 Turn SW 3 to air.

6.12 After thirty seconds turn the process selector switch to position 2.

6.13 Assure that all pallets have passed through the infrared oven.

6.14 After the final pallet has exited the oven position SW 6 in the off position.

6.15 Reduce CV 3 to maximum counter clockwise position.

6.16 Put SW 2 in the off position.

6.17 Put SW 5 in the off position.

6.18 Remove the alternative collection vessel and replace it with another.

6.19 Remove pump reservoir pot and empty into a clean container for reclaiming.

6.20 Return pump reservoir pot.

6.21 Turn selector switch to position 3.

6.22 Put SW 3 in solvent position.

6.23 Allow one-to-one and one-half gallons of solvent to purge the system.

6.24 Remove the nozzle and wing nut.

6.24.1 The nozzle and wing nut are to be immersed in solvent solution as soon as removed, and to be left covered until cleaned.

6.25 Put SW 7 in off position.

7.0 <u>Maintenance</u>

7.1 Prior to operation of machine check the aluminum slurry container and solvent container.

7.1.1 If either appears discolored discard, clean container and replace.

7.2 Clean wing nut and nozzle after each use.

7.2.1 Remove from stored solvent and rinse with fresh solvent.

7.2.2 Place in 400 ml glass beaker.

7.2.3 Cover with acetone.

7.2.4 Place in ultrasonic bath for five minutes.

7.2.5 Assure that all passages are clear and no residue remains on surfaces of either.

7.2.5.1 If residue is present, clean with soft cloth and repeat from 7.2.3.

7.2.5.2 If hole is closed, clean with tapered steel wire and repeat from 7.2.3.

7.2.6 Replace filters in the air dry section monthly.

7.2.7 Replace the filter under the conveyor bimonthly.

7.2.8 Empty the excess aluminum slurry.

8.0 <u>Safety</u>

8.1 Avoid contact with all solvents.

8.2 Avoid contact with the outside surface of the infrared oven -- it is hot.

8.3 Do not operate machine with the front safety glass off except during measurement times (see 5.15).

8.4 Insulated gloves must be worn during the unloading operation.

Prepared by: Clayton Olson Date: 4/3/80

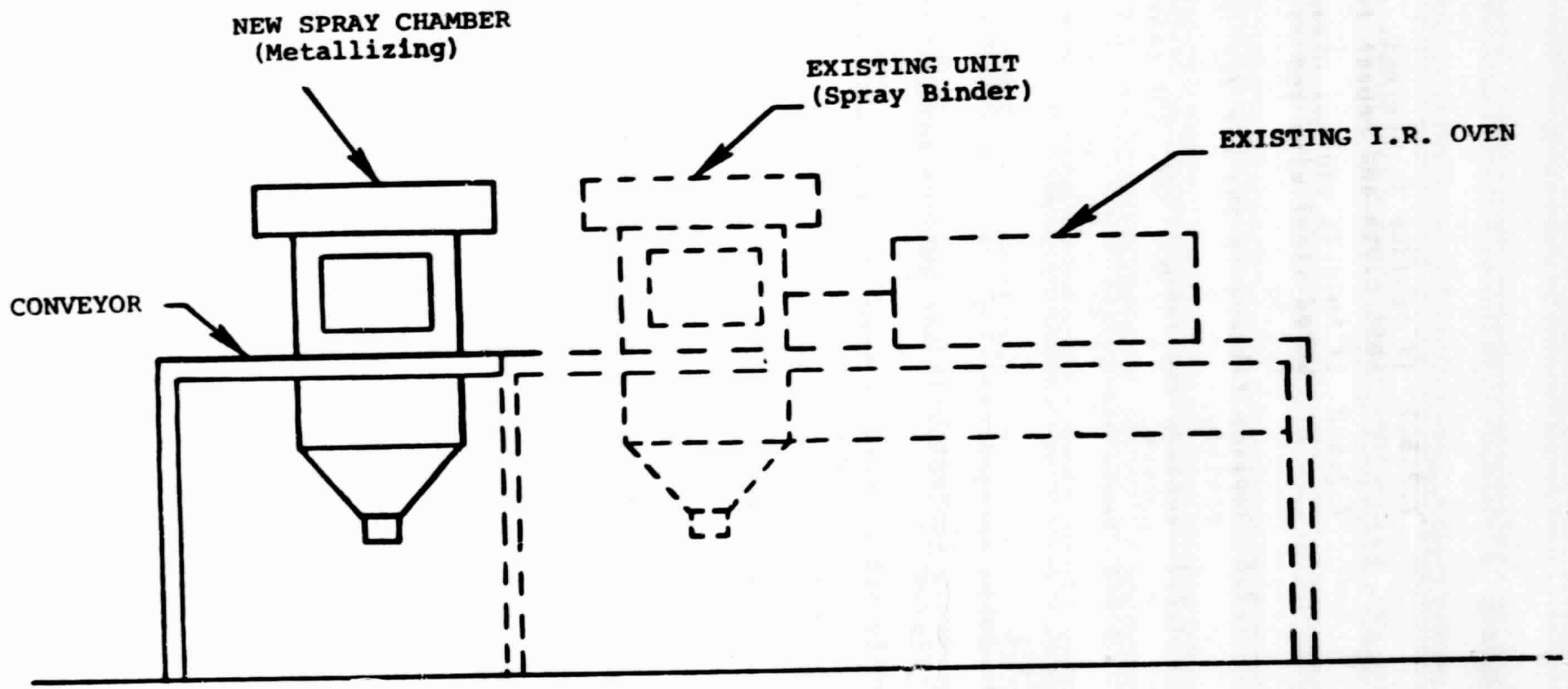
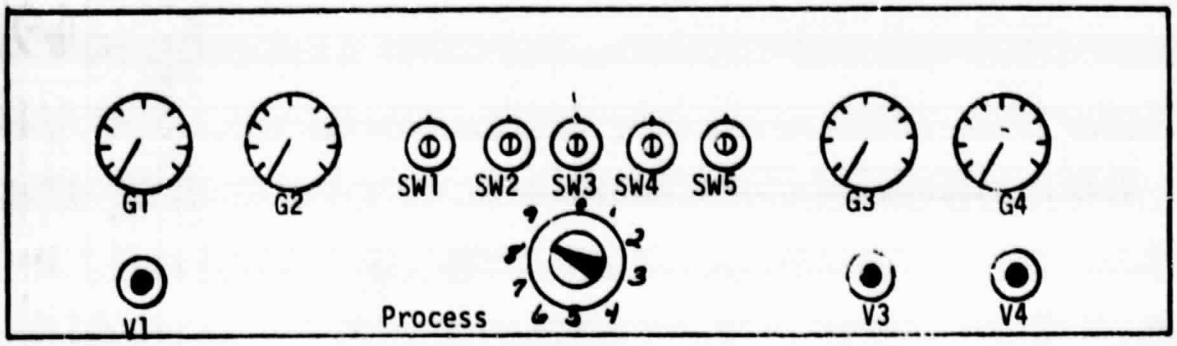


Figure 60. Illustration of the Modified Spray-on System for Applying Aluminum to the Back Surfaces of Solar Cells.



Gauges

G1 Low Pressure Control Manifold Gauge (PS16) 0-15
G2 Pressure Coating Material Gauge (PS16) 0-15
G3 Atomization Pressure for Spray Gun (PS16) 0-60
G4 Solvent Pot Pressure (PS16) 0-30

Control Knobs

V1 Low Pressure Manifold Control Valve
V3 Atomization Pressure for Spray Gun
V4 Solvent Pot Pressure Control Valve

Switches

SW1 Slurry Pump on-off Switch
SW2 Nozzle Reciprocator on-off Switch
SW3 Systems Purge Selection Switch for Solvent or Air
SW4 Spray Gun Selector Switch for Spray and Flush
SW5 Atomization on-off Switch

Process Selector Switch

Position

0	Off
1	Purge Waste Material
2	Off
3	Purge Pump
4-6	Not Utilized
7	Slurry Circulation
8	Off
9	Slurry Waste

Figure 61. Illustration of Control Panel of Aluminum Spray-on Module.

PX-02A(ALT)

Figure 62. Aluminum Spray Fixture.

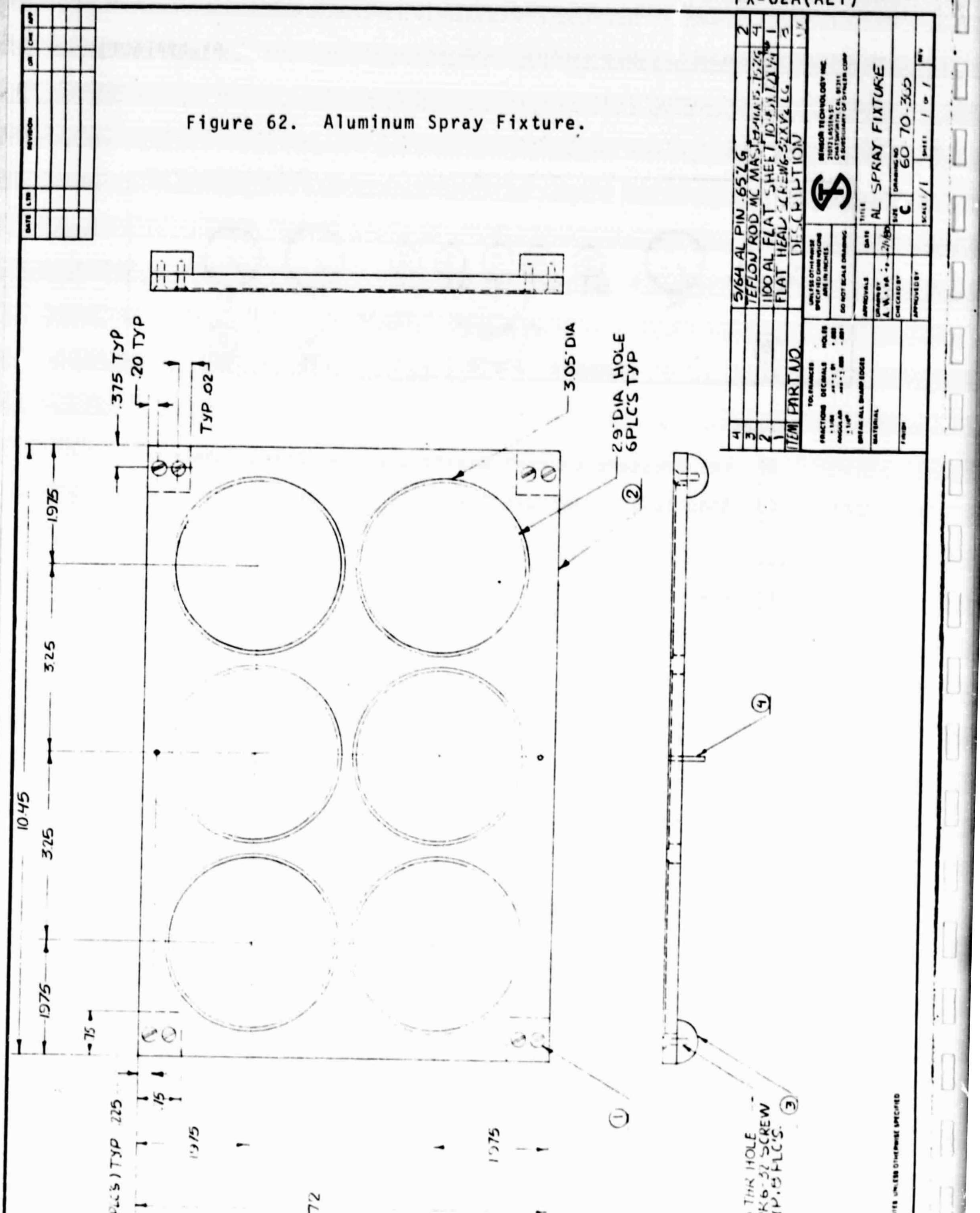
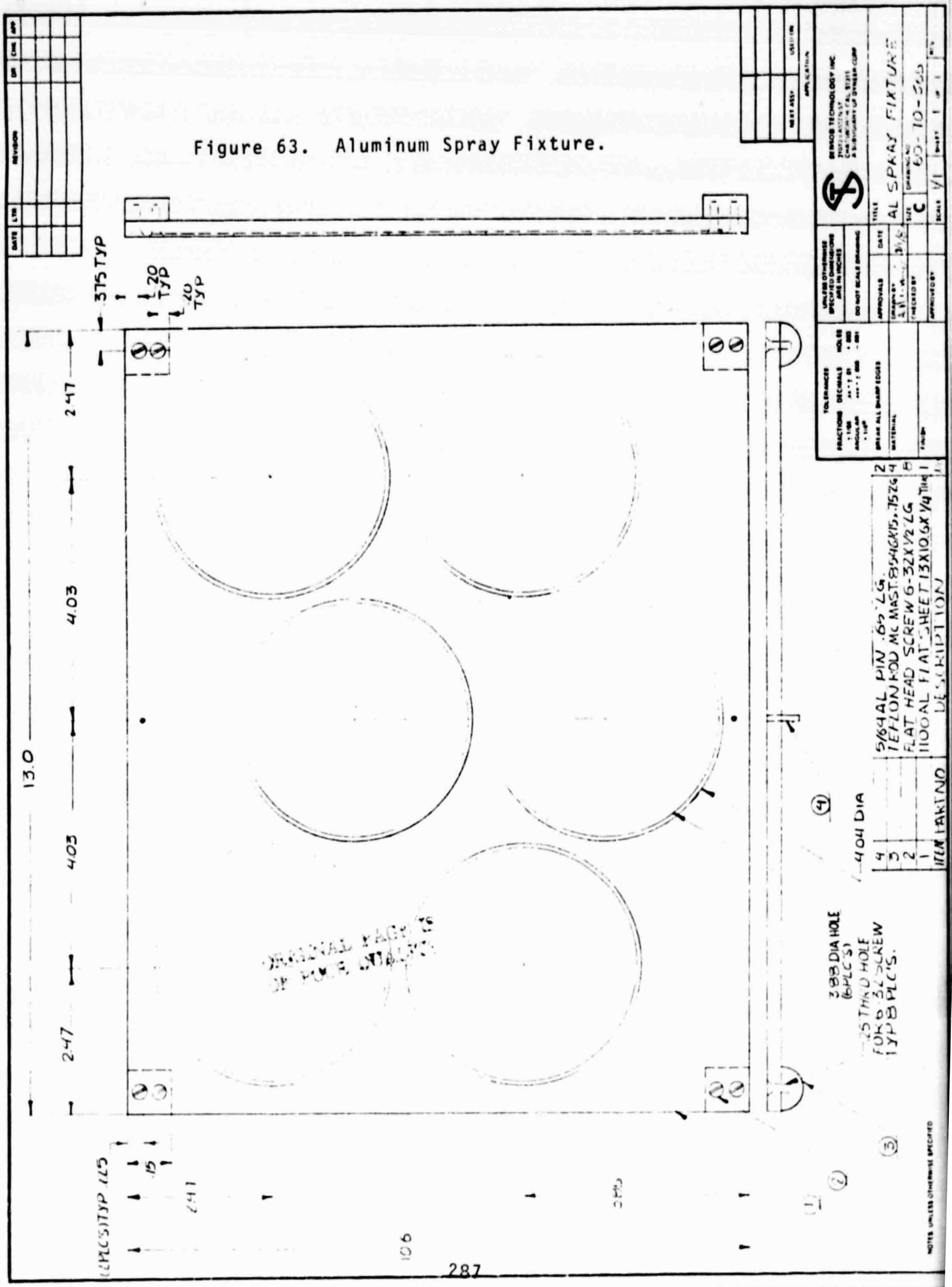


Figure 63. Aluminum Spray Fixture.



PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

COMPOUND ALUMINUM SLURRY

1.0 Object

1.1 To prepare slurry in a safe, uniform manner.

2.0 Material

2.1 Aluminum powder. Alcan Ingot and Powders (Elizabeth, N.J.) Number MD-X-65 or equivalent. Equivalent to be six micron diameter, atomized, spherical material.

2.2 Binder Solution. Hughson Chemicals (Erie, PA), Chemlock Primer AP-134.

3.0 Equipment

3.1 None

4.0 Supplies

4.1 Beaker, stainless steel, 4 liter capacity. Scientific Products B2712-4L or equivalent.

4.2 Graduated cylinder, 4 liter capacity, glass.

4.3 Graduated cylinder, 500 ml capacity, glass

4.4 Scoop, metal or glass, appropriate for 300 to 400 cc of aluminum powder.

4.5 Stir rod, 18 inches long by 1/2 inch diameter, aluminum or stainless steel.

4.6 Acetone, reagent grade.

5.0 Preparation

5.1 Remove static charges from all vessels and tools.

6.0 Procedure

6.1 Pour 3785 ml of binder solution into stainless steel beaker.

6.2 Measure 330 ml of aluminum powder into the 500 ml graduated cylinder. (See safety).

6.3 Slowly pour the aluminum powder into the binder solution while stirring the solution/mixture.

6.4 Mix until uniform.

PAGE 288 INTENTIONALLY BLANK

7.0 Maintenance

7.1 All supplies must be cleaned with acetone immediately after use and stored in a non-contaminating manner.

8.0 Safety

8.1 Do not expose aluminum powder to an open flame.

8.2 Do not pour aluminum powder in a manner which will create a cloud. In such form rapid oxidation can occur with a resultant explosion.

8.3 Do not mix aluminum powder with even mildly oxidizing media.

8.4 In the event of spillage do not vacuum the aluminum powder.

8.5 Remove static electricity from all material being used and the operators.

8.6 In the event of spillage, sweep up the spilled powder in a dry manner. Do not wet down the area.

8.7 It is recommended that all supervisory and engineering personnel familizarize themselves with the contents of the pamphlet, "Recommendations for Storage and Handling of Aluminum Pigments and Powder," Aluminum Association, Inc., 818 Connecticut Ave., N.W., Washington, D.C. 20006. This is also available through Alcan Ingot and Powders.

Prepared by: [illegible signature] Date: 11 7 80

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

(Outline Form)

DRIVE-IN

1.0 Object

The object of this process is to drive in the dopant or dopants deposited in the spray-on operation.

2.0 Material

The only input material is the doped wafers.

3.0 Equipment

A standard diffusion furnace is required.

4.0 Supplies

Two gasses are required. Both nitrogen and oxygen in the highest purity available within economic constraints. Quartz diffusion boats are also required.

5.0 Preparation

It is necessary to profile the furnace to $875^{\circ} \pm 5^{\circ}C$. The flow rates of the gasses are 500 cc/minute on oxygen and 1000 cc/minute on nitrogen. Load the boat.

6.0 Procedure

The boats are placed into the furnace at $875^{\circ}C$ for 45 minutes. They are pulled and allowed to cool in clean ambient atmosphere.

7.0 Maintenance

The usual cleanliness requirements apply.

8.0 Safety

Standard hot procedures and evolved gasses.

Prepared by: [illegible] Date: [illegible]

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION
(Outline Form)
PRINT FRONT SURFACE PATTERN

1.0 Object
This process outlines the manner in which a coating is applied to the front surface of the solar cell to limit the areas in which deposition of metal occurs.

2.0 Material
The wafers as received from the dopant drive-in process.

3.0 Equipment
A silk screen device, equipped with the appropriate silk screen and a viscosimeter are requried.

4.0 Supplies
A plating resist such as WARNOW PR-4001.

5.0 Preparation
Dilute the resist to the proper consistency with the appropriate diluent. If WARNOW 4001 is used, dilute to 600,000 cp with Colonial ER48073.

6.0 Procedure
Place wafer against stops with diffused side up. Activate the machine after assuring that there is sufficient plating resist to properly cover the wafer.

Cure the resist at 130°F for 25 minutes if PR-4001 is used.

7.0 Maintenance
Preventive maintenance on the printer and proper clean up after use apply.

8.0 Safety
Standard solvent handling and hot oven procedures apply.

Prepared by; Taylor Clark Date; 1/26/81

PAGE 292 INTENTIONALLY BLANK

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

ELECTROLESS NICKEL PLATE

1.0 Object

1.1 This specification outlines the manner in which the plating operation is performed.

2.0 Material

2.1 Wafers from the "Print Front Surface Pattern" operation.

3.0 Equipment

3.1 Plating module consisting of

3.1.1 Hydrofluoric acid tank to hold 8 liters (6" x 16" x 10").

3.1.2 Gold solution tank to hold 8 liters (6" x 16" x 10").

3.1.3 Overflow rinse tank to contain 30 liters (14" x 16" x 12").

3.1.4 Four 8 liter Corning VC-8 fast heating baths for nickel plating each containing an automatic heat control and agitation units.

3.2 A two-stage cascade rinse unit, each stage of which has a 30 liter capacity and a nitrogen bubbler. The design of the bubbler is not critical. Each tank is 14" x 16" x 10".

4.0 Supplies

4.1 Wafer carriers, teflon, 25 wafer capacity, with handles.

4.2 Concentrated hydrofluoric acid, electronic grade.

4.3 Electroless gold plating solution SG-10 from Transene Company, Inc., Rowley, MA.

4.4 Electroless Nickel Plating Ammonia Type from Transene Company, Inc.

4.5 Nitrogen gas, industrial, dry.

4.6 Deionized water.

4.7 Acid resistant gloves.

4.8 Safety apron.

4.9 Faceshield.

5.0 Preparation

5.1 Prepare 8 liters of 10% hydrofluoric acid (v/v) in the first tank.

5.2 Prepare 8 liters of electroless gold in the second tank per instructions on container.

5.3 Prepare three of the nickel plating baths with 8 liters of solution each.

5.4 Turn on the heaters for the three tanks in 5.3 and adjust to $80^{o}C \pm 2^{o}C$.

5.5 When the plating solutions in 5.4 have attained the proper temperature turn on the deionized water in both the overflow rinse tank and the cascade system.

5.6 Adjust flow of both rinses to 1.5 gallons/minute.

5.7 Turn on nitrogen bubbler and adjust flow-rate to 10 liters/minute.

6.0 Procedure

6.1 Place one container of wafers into the diluted hydrofluoric acid tank.

6.2 After thirty seconds, transfer it rapidly to the gold plating tank.

6.3 After thirty seconds, transfer the carrier to the overflow rinse tank.

6.4 Repeat steps 6.1 through 6.3 until six containers of wafers are in the overflow rinse tank (overlap steps).

6.5 After four minutes of rinsing on the last container, transfer two containers to one of the charged nickel plating tanks.

6.6 Repeat 6.5 twice.

6.7 After four minutes of plating in the nickel tanks, tranfer the containers to the first stage of the cascade rinser.

6.8 After four minutes of rinsing in the second stage of the cascade rinse the units are transferred to the "Remove Resist" process.

6.9 Initiate process 6.1 in five minute intervals for continuous processing.

7.0 Maintenance

7.1 Replace the diluted hydrofluoric acid solution after 8100 wafers (324 container loads).

7.2 Replace the gold plating solution after 11,700 wafers (468 containers).

7.3 Replace the nickel plating solution on a three hour cycle.

7.3.1 Prepare fourth tank as in 5.3 and 5.4.

7.3.2 Empty one of the used nickel tanks.

7.3.3 Rinse the tank emptied in 7.3.2.

7.3.4 Prepare the nickel plating solution as in 5.3 and 5.4.

7.3.5 When the solution proposed in 7.3.4 is at the proper temperature, repeat 7.3.2 through 7.3.5 until until all three original tank loads have been replaced.

8.0 Safety

8.1 All personnel within the area are required to wear safety equipment.

8.2 Refer to MCA Specifications for proper handling of ammonia hydroxide, hydrofluoric acid and cyandide containing solutions.

Prepared by: [illegible] Date; [illegible]

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

REMOVE RESIST

1.0 Object

1.1 The purpose of this specification is to outline the method by which the resist applied in "Print Front Surface Pattern" is removed.

2.0 Material

2.1 Wafers from "Electroless Nickel Plate" operation.

3.0 Equipment

3.1 Fluoroware Rinser/Dryer or equivalent.

3.2 Hot water cascade and bubbler.

3.3 Stainless steel stripper line with ultrasonic agitator.

3.4 Polypropylene container of sufficient size to hold three cassettes and a minimum of eight inches in height.

3.5 Timer, Gra-Lab or equivalent.

3.6 Oven, circulating, capable of 105^{o} to $115^{o}C$ and holding 20 twenty-five wafer cassettes.

4.0 Supplies

4.1 Stripper AP232, Inland Specialty Chemical Corp. (Orange, CA).

4.2 Methanol, reagent grade.

4.3 Wafer cassettes, teflon.

4.4 Exhaust system capable of 1000 CFM.

5.0 Preparation

5.1 Load all nine stripper holding containers to a six inch depth with AP232.

5.2 Load polypropylene container to a six inch depth with methanol.

5.3 Turn-on hot water bubbler and cascade.

5.3.1 Do not commence operation until the exit temperature is greater than $50^{o}C$.

5.4 Turn on stripper ultrasonic switch.

5.5 Place acid handles into cassettes.

5.6 Turn on oven and set temperature to $105^{o}C$-$115^{o}C$.

6.0 Procedure

6.1 Place one cassette into each of the three rear stripper containers.

6.2 Allow to remain in containers for three minutes.

6.3 After three minutes, transfer initial cassettes to middle row of stripper containers.

6.4 Immediately place three additional cassettes into rear row.

6.5 After three minutes, transfer cassettes from middle row to front row and those from back row to the middle row, again loading a new group of three to the back row. (See Maintenance.)

6.6 After another three minute interval, remove the three cassettes from the front row, quickly blot excess stripper from the bottoms and place them in the methanol container.

6.7 Repeat 6.1 through 6.5.

6.8 After three minutes, remove the cassettes from the methanol, quickly blot the bottoms and place in the third stage of the hot water rinse.

6.9 Repeat 6.1 through 6.7.

6.10 Stage the cassettes through the hot water cascade in three minute intervals in the same manner as was done with the stripper.

6.11 Repeat all stepping operations.

6.12 After the final hot water step, remove the cassettes, quickly blot the excess water and place in the oven for 10 to 15 minutes.

6.13 Pass along the next operation.

7.0 Maintenance

7.1 Monitor oven temperature each hour.

7.2 Stripper tanks are to be rotated as follows.

7.2.1 Discard the rear group of three.

7.2.2 Empty the middle group of three into the rear group.

7.2.3 Empty the front group into the middle group.

7.2.4 Replace the front group with fresh AP232.

NOTE: The above (7.2) operation can be accomplished by changing the physical placement of the containers.

7.3 Replace methanol when a foaming action occurs on the surface of the hot water cascade rinse.

8.0 <u>Safety</u>

8.1 Perform stripping operation under a hood.

8.2 The stripper contains a combination of methylene chloride and toluene. Refer to MCA specifications for toxicity values for inhalation, ingestion and surface contact.

8.3 Observe standard safety precautions for hot items (oven and cassettes) and use of methanol.

<u>NOTE</u>: This procedure, although not automated for 1986 goals, is capable of such automation. It is presented here, in this manner, to indicate the steps required.

Prepared by: [illegible signature] Date: 11/3/80

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

LASERSCRIBE

1.0 Object

1.1 This specification delineates the requirements and procedures for producing hexagonal wafers with center holes for insolated side connection.

2.0 Material

2.1 Wafers from "Remove Resist" process.

3.0 Equipment

3.1 Quantronix Corporation (Smithtown, NY) Model 603-2 Laserscribe or equivalent.

3.2 Program board for hexagon and circle program on laser-scribe.

4.0 Supplies

4.1 Cooling water at 3 gallons/minute.

4.2 Deionized water at 10 cc/hour.

4.3 Cotton gloves.

5.0 Preparation

NOTE: The following procedure applies to the creation of 3.52 inch (major diameter) hexagonal cells from 3.54 inch diameter round cells. Appropriate modifications must be made when other sizes are to be used or produced. Additionally, the operational description applies to the Quantronix 603-2 only.

5.1 Place the X and Y switches in the off position.

5.2 Turn the master switch key to the on position.

5.3 Depress reset button located on the C board.

5.4 Turn on X and Y motor switches.

5.5 Set the auxiliary power supply to 35 amperes.

5.6 Set the auxiliary digiswitches as follows:

5.6.1 Wafer diameter - 3.8 inches.
5.6.2 Pulse rate - 12 KHz
5.6.3 Table speed - 8 inches/second.

5.7 The large hexagon scribing routing is obtained with the MCS option digiswitch in positions C through F. In each position a hexagon is scribed with a corner-to-corner diagonal equal to twice the diagonal digiswitch setting in units of 10 mils. For example, a setting of 185 produces a hexagon with a diagonal of 3.7 inches. The allowable settings are from 100 to 199. The length of the strokes taken to generate

5.7 (Continued)

each side is determined by a calculated wafer diameter equal to the diagonal plus ¼ inch. Scribe lines are extended to exceed the wafer diameter to expedite cracking. For accurate scribing the velocity should be set at 4 ips or less using the HEX VEL Digiswitch on the front panel. In addition, the corners of the hexagon may be cut at a distance from the vertex as given by the truncate digiswitch in mils, thus generating a non-regular 12-sided figure. The minimum cutoff is equal to 4 times the speed in inches per second; the maximum cutoff is equal to ¼ of the diagonal or 100 mil, whichever is less. Setting the truncate digiswitch at values outside these limits will cause the cycle to abort after scribing the basic hexagon. If no cutoff is desired the truncate digiswitch should be set at zero.

5.8 Option position functions are:

5.8.1 Position B. Center hole generation only.

5.8.2 Position C. Center hole and hexagon.

5.8.3 Position D. Hexagon is generated and then bisected along the Y axis producing two pentagons.

5.8.4 Position E. Hexagon is generated and then bisected along the X-axis, producing two trapezoids.

5.8.5 Position F. Hexagon is generated.

5.9 With the option position switch in position B or C a hole is cut in the wafer with its center at the center of the wafer within $\pm$ 5 mils. The diameter of the hole is given by the setting of the hole diameter digiswitch in increments of 10 mils. The minimum diameter is 100 mils and the maximum is 500 mils; settings outside these limits will not be accepted by the program. The speed and number of passes around the circle required to completely remove the circular plug is a function of wafer thickness and cut edge quality. To permit system optimization these parameters may be selected by the operator. The number of passes is given by the pass digiswitch times 4, the speed is given by the MCS velocity digiswitch in its normal format. Typical values of these parameters are 20 passes at 2 ips for an effective cutting rate of 0.1 ips or 3 seconds for an 0.1 inch diameter hole. In option position B only the above hole is generated. In option position C both the hole and the hexagon are generated. Typical parameters utilized in option position B are as follows.

Power:	17.5 watts
Cycle:	10 KHz
Table Speed:	2 in/sec
No. of Passes:	12
Cutting Time:	10 seconds
Hole Diameter:	0.2 inches

6.0 Procedure

6.1 Load wafers into fixture located on dual axis travel table with active side down.

6.2 Depress wafer hold switch.

6.3 Close safety door.

6.4 Depress run switch.

6.4.1 Operator observes the scribing operation through the microscope. In the event of a failure, the operator depresses the stop/start switch.

6.5 When the cycle is completed the laser will be turned to a standby mode and the doors will open.

6.6 Unload the wafer.

6.7 Repeat from 6.1 until all wafers are scribed.

6.8 Place clean cotton gloves on hands and, holding the wafer with the scribe line up:

6.8.1 Grasp wafer with thumb and finger tips, not including the body of the hand.

6.8.2 With the thumb and index finger of the other hand grasp the wafer just outside the scribe line at its midpoint.

6.8.3 Exert a downward, torquing force on the wafer until it snaps.

7.0 Maintenance

7.1 The illumination lamp must be replaced every 50 hours.

7.2 The krypton lamp must be replaced every 250 hours.

7.3 The filter must be replaced every 1000 hours.

8.0 Safety

8.1 Never look directly into the laser.

Prepared by: [illegible signature] Date: [illegible]

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION
(Outline Form)
SOLDER COAT

1.0 Object

This specification outlines the technique by which a solder coating is placed on the back and front surfaces of the cell.

2.0 Material

Wafers from the "Laserscribe" operation and tin/lead (60/40) solder are required.

3.0 Equipment

An overflow solder pot of appropriate dimensions to accept the teflon holding fixtures. A preheater oven is also required.

4.0 Supplies

Teflon carriers with retainer bars to prevent floating of the wafers in the solder are required. These carriers must hold the wafers in a vertical position. A ten inch handle is recommended. Water soluble flux is also required.

5.0 Preparation

Load the carriers with wafers. Set the preheating oven to $175^{o} \pm 15^{o}F$. Set the solder pot to $475^{o}F + 25^{o}F$.

6.0 Procedure

Dip carrier load of wafers into the water soluble flux.

Place the carriers into the oven for a minimum of five minutes.

Remove from the oven and immerse in the solder bath for 5-10 seconds.

Remove from the bath and impact the load against a hard surface to dislodge excess solder. This may be omitted if an air knife system is installed above the solder pot.

Lay carrier on its end so that wafers are horizontal.

When cooled remove wafers and pass along to the "Remove Flux" operation.

7.0 Maintenance

Add solder to the pot as required.

8.0 Safety

Standard hot material procedures apply.

Prepared by; [signature] Date; 11/11/81

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

(Outline Form)

REMOVE FLUX

1.0 Object

To remove the flux from cells after solder coating.

2.0 Material

Wafers from the solder coat operation.

3.0 Equipment

A three stage hot water cascade system with built-in ultrasonic agitation in the first stage.

4.0 Supplies

Standard wafer carriers are required. Hot D.I. water at an input temperature range of 90°-95°C is also needed.

5.0 Preparation

Start flow of hot D.I. water into cascade. Load wafers into carriers. Check the input temperature and, when hot enough, start the ultrasonic agitator.

6.0 Procedure

Place the carriers into the first tank for two minutes. (This is the first tank of operation and the third tank in the cascade cyclc.) Step the carriers through the cascade progression in two minute intervals. Air dry in a clean environment.

7.0 Maintanance

Be certain flux residue does not build-up. If this starts, scrub and rinse with hot D.I. before the next use.

8.0 Safety

The standard hot water regulations apply.

Prepared by: Raylon Elwoo Date: 11/3/80

PRECEDING PAGE BLANK NOT FILMED

PHOTOWATT INTERNATIONAL, INC. PX-09

ENGINEERING SPECIFICATION

(Outline Form)

Si_3N_4 AR COAT

1.0 Object

The object of this process is to apply an antireflective coating to the cell.

2.0 Material

Wafers from the "Remove Flux" operation.

3.0 Equipment

An LFE Corporation, Process Controls Div. (Waltham, MA) System 8000.

4.0 Supplies

One and one-half percent silane in argon is the only supply.

5.0 Preparation

The following parameters are inputs to the microprocessor which completely controls the operation:

Thickness: 800Å
Deposition Rate: 1200 Å/minute
Gas Flow Rate: 4.125 ft^3/hour
Process Rate: 300 wafers/hour

6.0 Procedure

Since the process is entirely controlled by the microprocessor, it is only necessary to load two 25 wafer cassettes onto the input unit and two empty 25 wafer cassettes onto the output end and turn the machine on. The cassettes must be replaced as exhausted or filled, of course.

7.0 Maintenance

Refer to the operating manual for the particular serial number machine in use.

8.0 Safety

The usual hazards associated with moving machinery and internal high voltages apply.

Prepared by: Clayton L. Cloze Date: 1/22/81

PAGE 310 INTENTIONALLY BLANK

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

(Outline Form)
LAMINATE (AUTOCLAVE)

1.0 Object

To laminate the module components into a complete functional assembly ready for framing and attachment of terminals.

For this contract, all lamination was done by Spectrolab, Inc.

The procedure used is indicated in Spectrolab Specification 6314-0021. This is given in the Final Report on Contract 954853 (to be published in 1980).

Prepared by: Clayton Olson Date: 1/3/80

PAGE 312 INTENTIONALLY BLANK

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATION

(Outline Form)
PERFORMANCE TEST

1.0 Object

This specification outlines the procedure for performance testing of the final module prior to packaging for shipment.

2.0 Material

The module to be tested.

3.0 Equipment

A solar simulator with sufficient span and adequate tolerance and the program illustrated in the attached figures are required along with the printout medium selected.

4.0 Supplies

The only supply required is paper for the printout type desired.

5.0 Preparation

Turn on the simulator, balance and calibrate it. Turn on the programmer and allow the required warm-up. Run a standard panel for calibration and functional checkout.

6.0 Procedure

Place modules into feed mechanism. Since this will vary from company to company, no specifics are possible. Subject to program shown and store by classification.

7.0 Maintenance

This is highly dependent upon the mechanics of the feed mechanism selected. Electronic maintenance should be automated and require service only at such time as warning indicators direct so.

8.0 Safety

The only safety precaution is to refrain from looking directly into the illumination source in the simulator.

Prepared by: Clayton Clever Date: 11/3/80

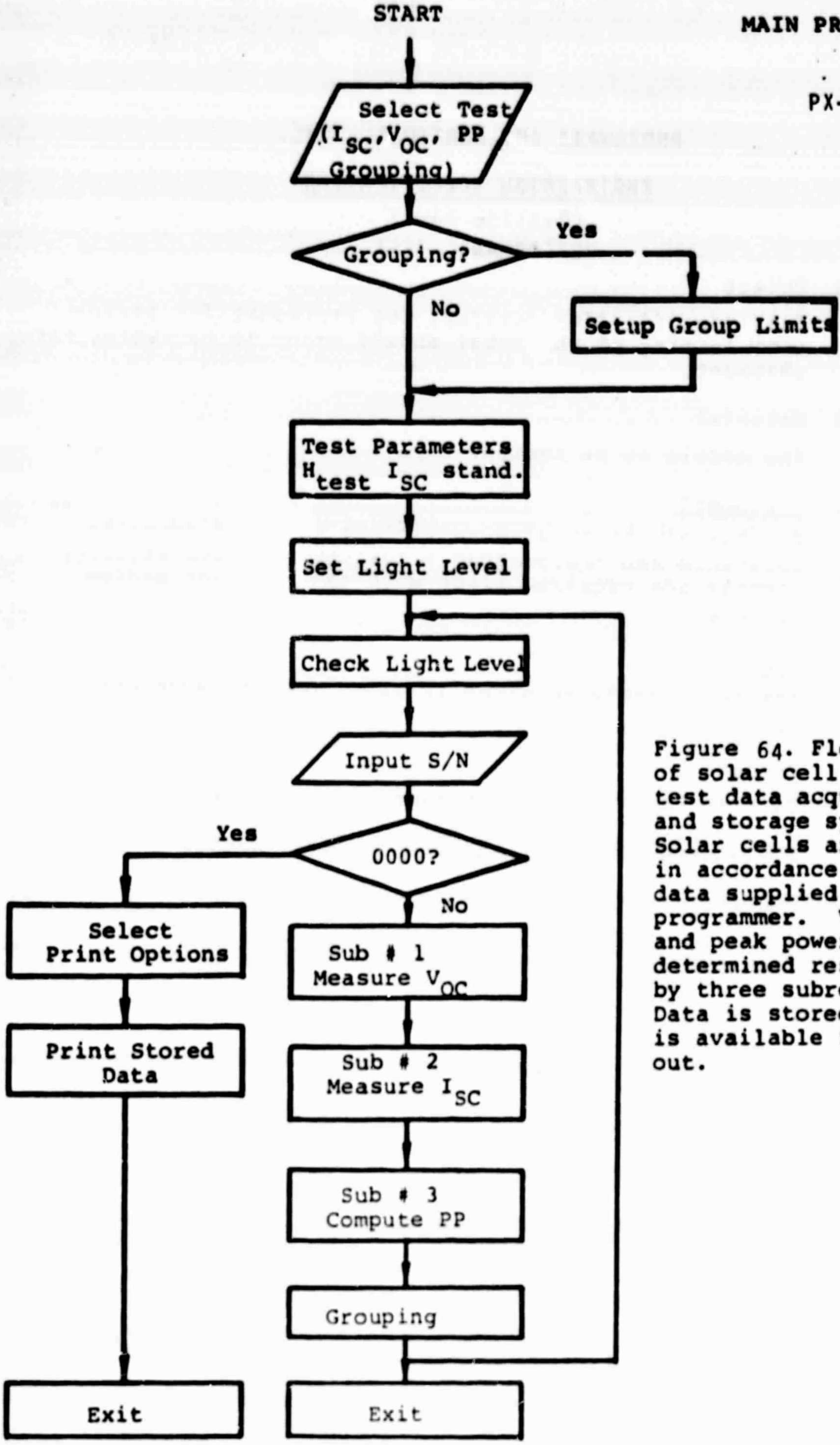


Figure 64. Flow chart of solar cell and module test data acquisition and storage system. Solar cells are grouped in accordance with input data supplied by the programmer. Voc, Isc and peak power are determined respectively by three subroutines. Data is stored and is available for print out.

SUBROUTINE # 1, V_{OC}

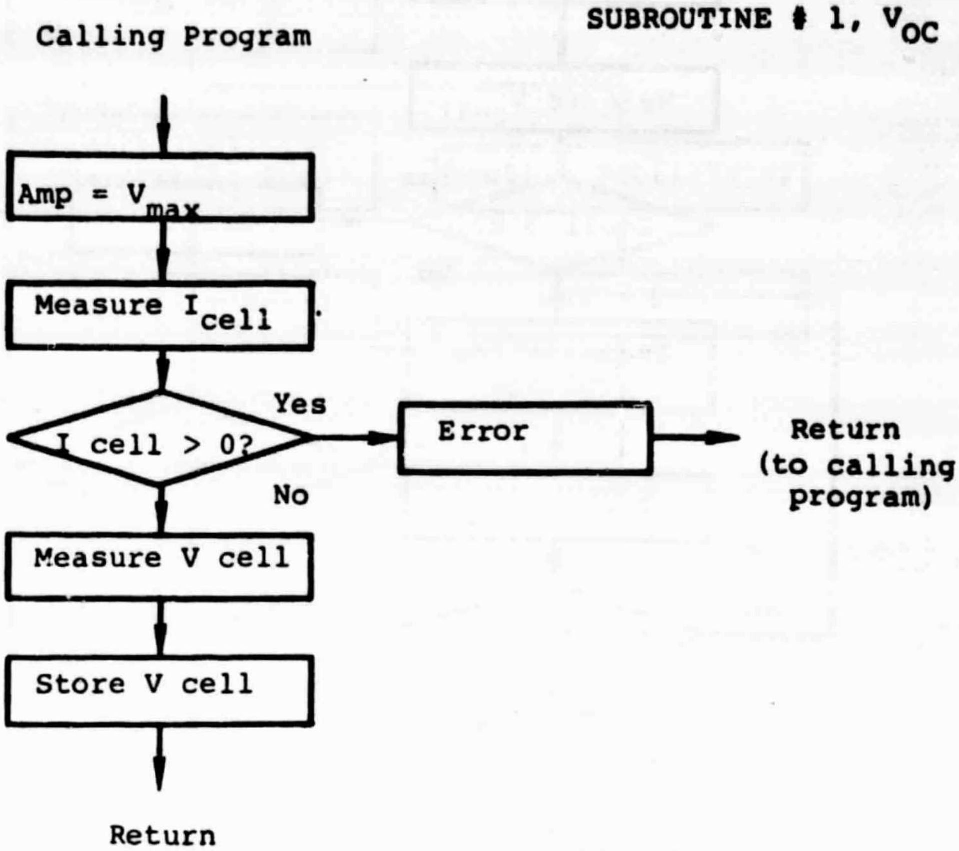


Figure 65. Flow chart of subroutine number one for measuring open circuit voltage of solar cells or module.

Note: Amp V_{in} is set to a maximum. This effectively discounts the unit under test from the load so that V_{oc} may be measured. I_{cell} is checked first and if it is greater than zero then an error occurs because Voc is higher than what the equipment can measure.

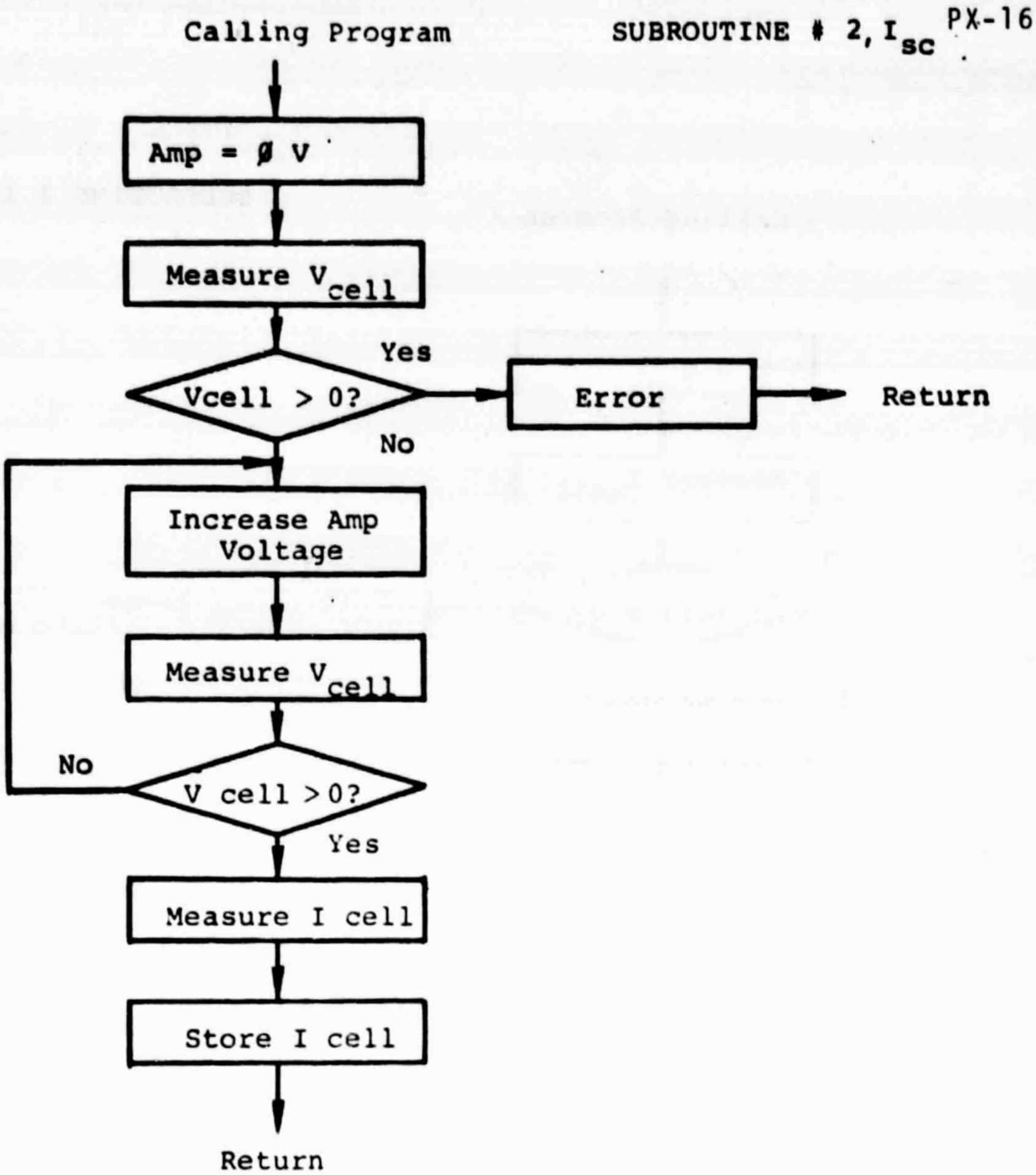


Figure 66. Flow chart of subroutine number two to measure short circuit current of solar cell or module.

Note: Amp Vin set to Ø V: If V cell is greater than zero then equipment is unable to measure Isc. Amp Vin is increased until Vcell is greater than zero. I cell is then measured and stored.

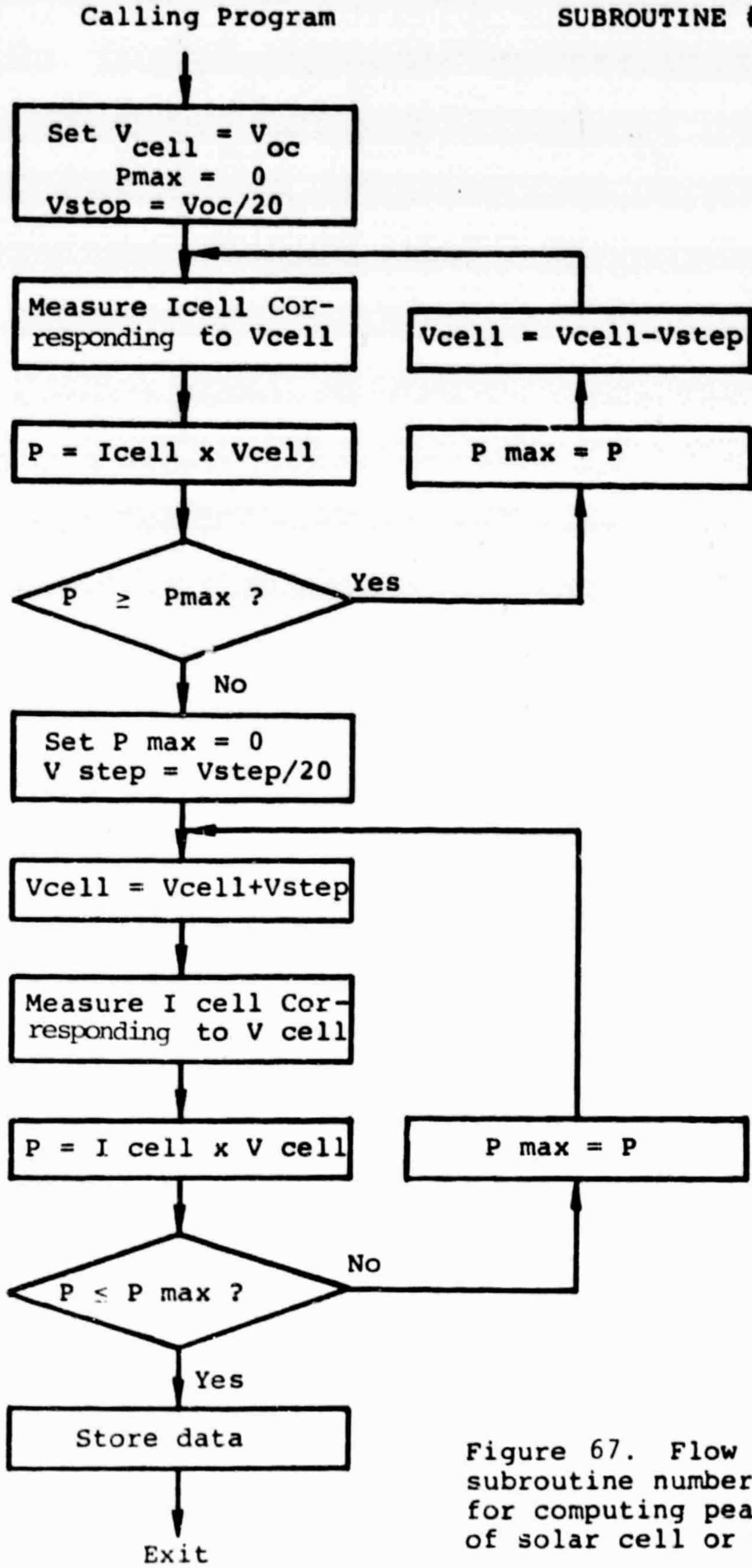


Figure 67. Flow chart of subroutine number three for computing peak power of solar cell or module.

PHOTOWATT INTERNATIONAL, INC.

ENGINEERING SPECIFICATIONS

The following specifications are all dependent upon cell pattern or internal specifications and therefore are not included.

PX-10 Test and Group
PX-11 Cell Interconnect
PX-12 Module Layup
PX-13 Degas
PX-15 Assemble Frame & Terminal

There are no specifications covering "Package" or "Ship".

Prepared by: [illegible signature] Date: 2-11-[illegible]

 320 INTENTIONALLY BLANK